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Agricultural Pesticide Use Trends and Policy Issues

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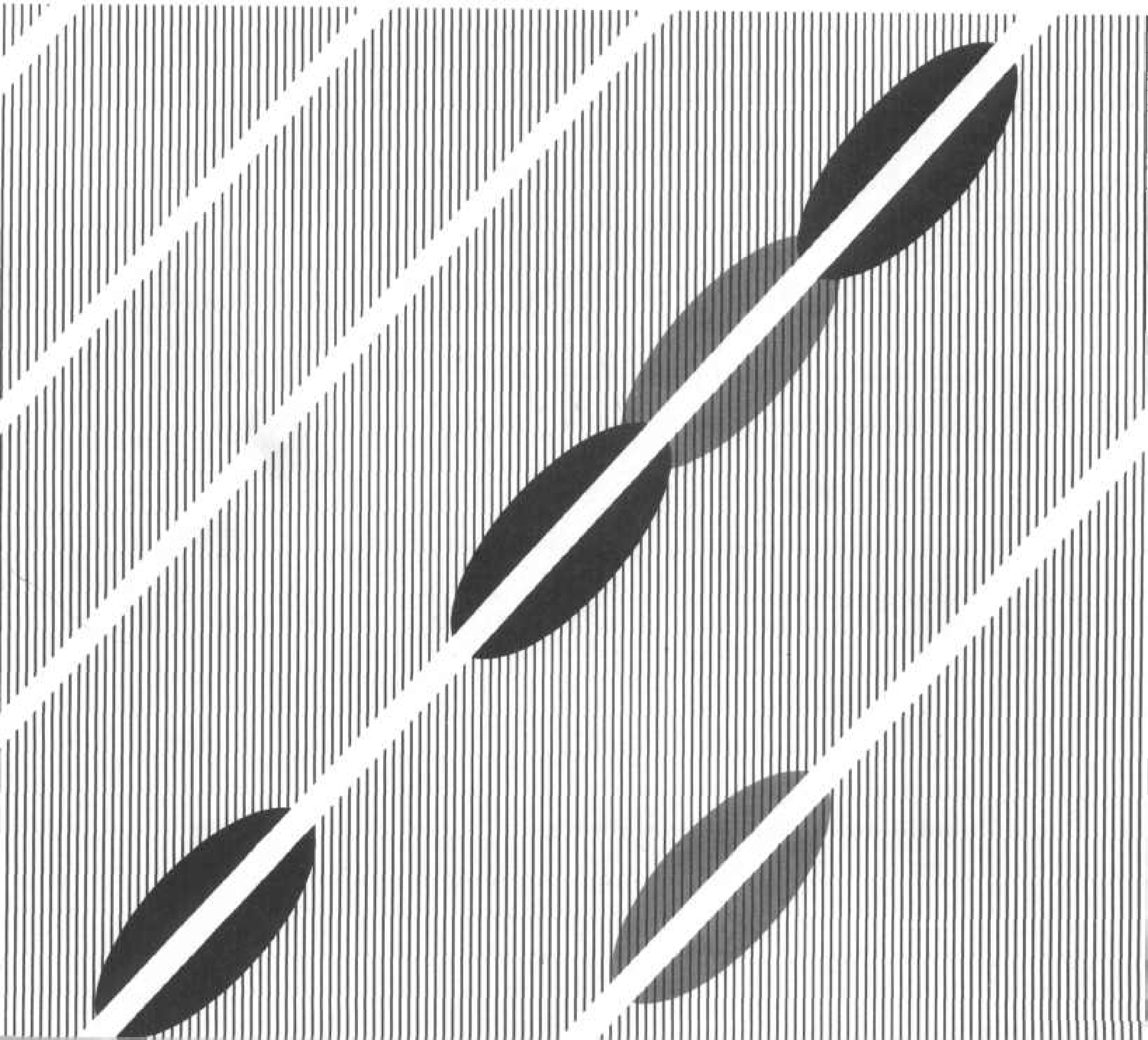

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AGRICULTURAL PESTICIDE USE TRENDS AND POLICY ISSUES. By Craig D. Osteen and Philip I. Szmedra, Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture. Agricultural Economic Report No. 622.

Abstract

Pesticides used on major crops increased from 225 million pounds of active ingredient (the material in a pesticide product that controls pests) in 1964 to 558 million pounds in 1982. Rapid growth in the use of herbicides led that dramatic increase. Farmers increased their use of pesticides on corn and soybeans to a greater extent than on other crops during that period. Insecticide use on cotton fell, probably because the pyrethroid insecticides, which are applied at low rates, were introduced in the late 1970's. Since 1980, pesticide use has stabilized or declined. Regulatory decisions that removed pesticides from the market if health or environmental risks outweighed the economic benefits may have reduced the variety of pesticides available to farmers. But, those decisions apparently have not slowed the growth of pesticide use.

Keywords: Pesticides, insecticides, herbicides, pesticide productivity, pesticide regulation, commodity programs, benefit assessment.

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Contents

Highlights

Pesticides used on major crops increased from 225 million pounds of active ingredient (the material in a pesticide product that controls pests) in 1964 to 558 million pounds in 1982. Rapid growth in the use of herbicides led that dramatic increase. Farmers increased their use of pesticides on corn and soybeans to a greater extent than on other crops during that period. The quantity of insecticides used on cotton fell, probably because pyrethroid insecticides, which are applied at low rates, were introduced in the late 1970's. Since 1980, pesticide use has stabilized or declined. Regulatory decisions that removed pesticides from the market may have reduced the variety of pesticides available to farmers. But, those decisions apparently have not slowed the growth of pesticide use.

Only about 10 percent of the cropland planted to corn, cotton, and wheat was treated with herbicides in 1952, but the share climbed to 90-95 percent by 1980.

Since 1980, pesticide use has stabilized or declined because of acreage decreases resulting from low crop prices and acreage diversion programs. Those acreage declines were most dramatic in 1983 during the implementation of the Payment-in-Kind Program.

Farmers doubled the amount of insecticide used on corn and soybeans from 1964 to 1982 and increased the amount of herbicide they used on those crops twelvefold during that period. Thus, pesticide use grew faster in the Corn Belt and Lake States, where those crops are concentrated, than in other regions.

Insecticide use on cotton fell from 78 million pounds of active ingredient in 1964 to 17 million pounds in 1982. During that period, the percentage of cotton acreage treated ranged from 50-65 percent.

Numerous safety concerns have faced regulators of pesticides: toxicity to humans, chronic health effects, food safety, surface and ground water pollution, and wildlife mortality. Regulatory decisions since the early 1970's may have reduced the number of pesticides available to farmers.

Agricultural Pesticide Use Trends and Policy Issues

Craig D. Osteen
Philip I. Szmedra*

Introduction

Farmers use a variety of methods, including pesticides, cultural methods, and pest monitoring, to prevent yield losses from pests. Agricultural pesticide use in the United States has grown rapidly since the end of World War II, contributing to increased agricultural productivity. However, during the 1960's, potentially undesirable side effects of pesticide use became major issues. Some pest control specialists claimed that pesticide use could increase pest losses or control costs, but many groups in the general public expressed concerns about health, safety, and environmental effects.

This report illustrates pesticide use trends with U.S. Department of Agriculture (USDA) and Environmental Protection Agency (EPA) estimates, discusses factors affecting those trends, and presents major policy issues.

Pesticides and Technology

The growth of pesticide use is an integral part of the technological revolution in agriculture that generated major changes in production techniques, shifts in input use, and growth in output and productivity. In 1968, Carlson and Castle stated, "The mechanization revolution of the 1930's and 1940's has been augmented since 1945 by a biological revolution in terms of fertilizer, pesticides, and genetic stock" (9).1/ That biological revolution continues.

Because of these changes, farmers use more machinery, fuel, and agricultural chemicals, but less labor. These trends can be shown two ways. Indexes of total input use show that labor use (hired, operator, and unpaid family) fell 73 percent from 1947 to 1986 (fig. 1). Agricultural chemical use (fertilizers, lime, and pesticides) increased about eightfold during that same period. Machinery and mechanical power use indicators (interest and depreciation on

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* The authors are agricultural economists with the Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture. An earlier version of this report was a background paper for the USDA Working Group on Agricultural Chemicals in the Environment.

1/ Underscored numbers in parentheses indicate sources in the References section.

Pesticide Use, Policy Trends, and Farm Policies

Before 1944

Pesticide Policy: Insecticide Act of 1910--

- Protects consumers from fraudulent goods.
- Establishes general standards for insecticides and fungicides.

Pesticide Use and Agricultural Technology:

- Farmers use inorganic pesticides.
- Agricultural machinery becomes widespread on U.S. farms.

1944-64

Pesticide Policy:

- Federal Insecticide, Fungicide, and Rodenticide Act of 1947 (FIFRA) emphasizes labeling of contents; U.S. Department of Agriculture (USDA) administers the act.
- Policy debates reflecting public concerns of health and the environment swell with 1962 publication of Rachel Carson's Silent Spring.

Pesticide Use:

- Synthetic organic pesticides introduced, 2,4-D (2,4-dichlorophenoxy acetic acid) in 1944 and DDT (dichlorodiphenyltrichloroethane) in 1945.
- Insecticides widely used on cotton, fruits, and vegetables in 1950's.
- Dramatic growth of insecticide and herbicide use on major field crops begins in the 1950's.

Farm Policy:

- Support prices typically higher than market prices.
- Large acreage diversion and land retirement programs during 1955-64.

1964-72

Pesticide Policy:

- Federal regulations stress effects on health and the environment.
- 1964 FIFRA amendments create means to suspend or cancel product registrations.
- Environmental Defense Fund asks DDT cancellation in 1969.
- Congress establishes Environmental Protection Agency (EPA) in 1970 to administer pesticide regulatory function of FIFRA and Federal Food, Drug, and Cosmetic Act (FDCA).
- Federal Environmental Pesticide Control Act of 1972 (FEPCA) sets new health and environmental standards; requires reregistration of pesticides registered before 1972; mandates benefit-risk assessment.

Pesticide Use:

- Pesticide, especially herbicide, use on major field crops grows.

- o Organochlorine insecticide use declines as organophosphate and carbamate use increases.
- o Phenoxy herbicides' share declines as triazines', amides', and others' increase.

Farm Policy:

- o Support prices often greater than market prices.
- o Continued large acreage diversion or retirement programs.

1972-81

Pesticide Policy:

- o EPA increases regulatory activity.
- o Public concerns with organochlorines lead EPA to cancel registrations for many uses of DDT, aldrin, dieldrin, heptachlor, and chlordane.

Pesticide Use:

- o Pesticide, especially herbicide, use on major field crops continues to grow, approaching market saturation in late 1970's and early 1980's.
- o Insecticide use declines in late 1970's as pyrethroids are introduced.
- o Petroleum and pesticide prices increase throughout period.

Farm Policies:

- o Exports, farm income, and land values increase.
- o USDA switches to target price/loan rate system in 1973.
- o Market prices generally exceed target prices.
- o Retired and diverted acreage declines.

1981 - Present

Pesticide Policy:

- o Regulatory activity declines during early 1980's.
- o Concerns about endangered species, ground water grow in mid-1980's.
- o EPA cancels EDB and most uses of dinoseb, restricts use of alachlor.

Pesticide Use:

- o Quantity of pesticides used stabilizes, declines in some instances.
- o Acreage diversion and retirement programs decrease pesticide use.

Farm Policy:

- o Farm prices and incomes decline during much of period.
- o Diverted and retired acreage increases.
- o Target prices often exceed market prices, raising program payments.
- o Food Security Act of 1985 creates Conservation Reserve Program (CRP) and reduces loan rates and target prices.
- o USDA freezes farm program yields.

Figure 1
Indexes of input use

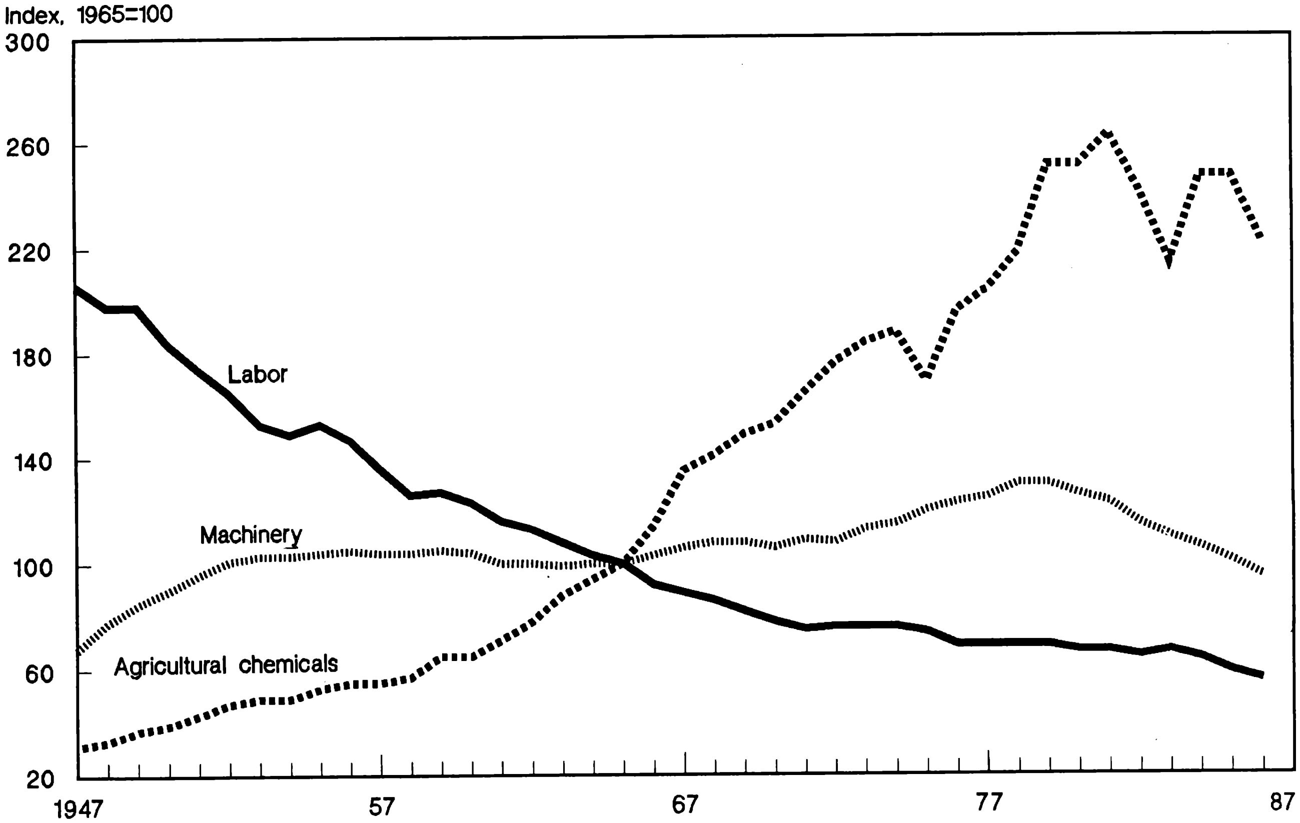
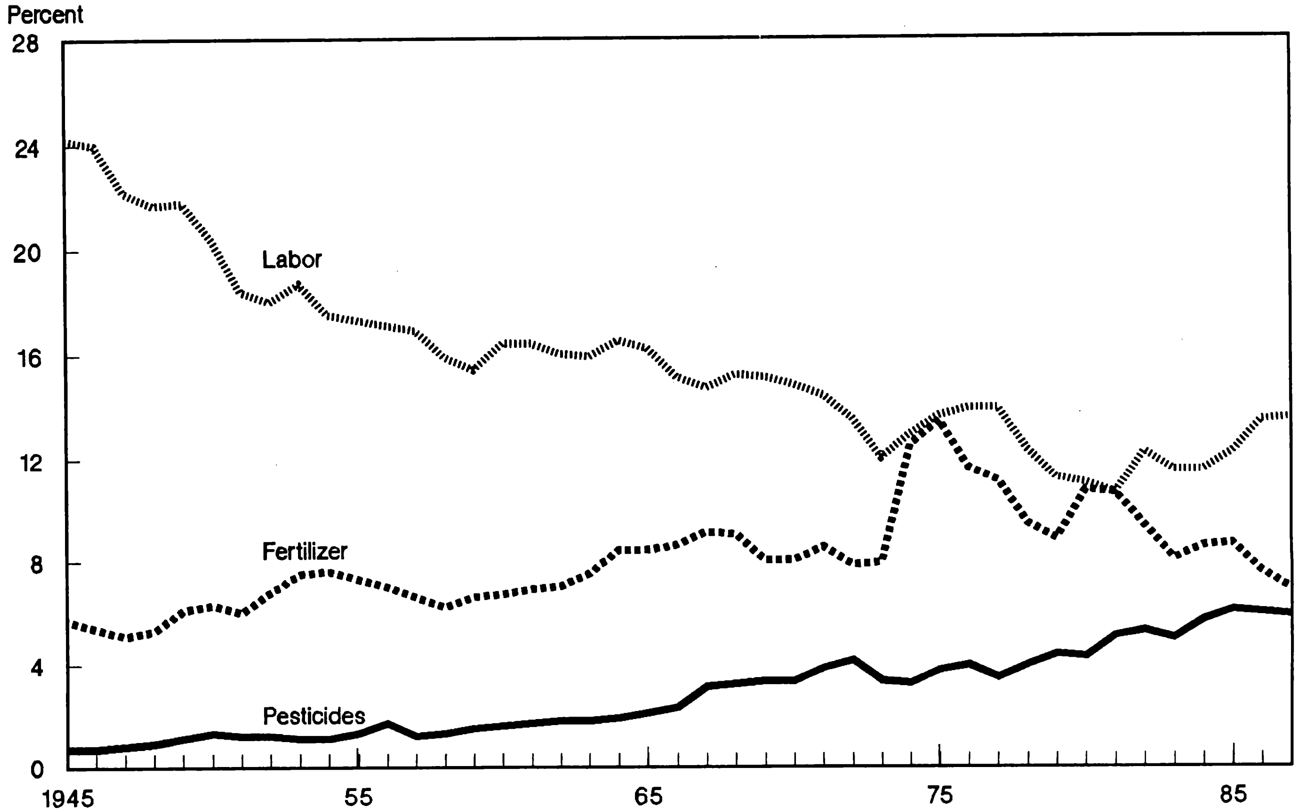


Figure 2
Pesticide, fertilizer, and labor costs as a share of operating expenses



mechanical power, machinery repairs, licenses, and fuel) grew by 93 percent from 1947 to 1979 but fell during the 1980's. Agricultural productivity (total output divided by total input) grew by 230 percent between 1947 and 1986 (77).

Pesticides' share of operating expenditures (excluding application and other pest control costs) grew faster than fertilizer's and manufactured inputs' shares (75). Pesticides' share is small, but it grew steadily from 0.7 percent in 1945 to 5.9 percent in 1986, increasing about ninefold. This increase reflects both changes in pesticide use and prices relative to other inputs. Fertilizer's share grew by 50 percent and total manufactured inputs' share grew by 75 percent during that period. However, the latter two percentages were higher from 1973 to 1980 because of high energy prices. Labor's share fell approximately 42 percent, from 24 to 14 percent, during the period (fig. 2).

Pesticide Use Trends

Before the 1870's, methods to control pest damage in crop production were primarily cultural and physical control practices such as crop rotation, destruction of crop refuse, timing of planting dates to avoid high pest population periods, use of trap crops, pruning and defoliation, and isolation from other crops (2). However, these measures could not manage all pests. Chemical pest control in agriculture originated with the development in the United States of paris green (copper acetoarsenide) in 1870 to combat the potato beetle, and the discovery of Bordeaux mixture (quicklime and copper sulfate) in France in 1882 to control disease in grape culture. Many scientists began extensive research into the methods and mechanics of chemical control during the early 20th century, despite warnings by colleagues and others in the scientific community against heavy reliance on pesticides. The plant pest control literature during 1900-65 demonstrates a preoccupation with the development of more resistant plant and seed varieties (principally against pathogens) and better chemicals, with comparatively little attention to biological and cultural controls (68).

The development and adoption of synthetic organic materials heralded the modern age of chemical pesticides. Two early synthetic organics were 2,4-D (2,4-dichlorophenoxy acetic acid), registered in 1944, and DDT (dichloro-diphenyltrichloroethane), registered in 1945. Synthetic organic pesticide use has grown more than the use of other pesticides since the end of World War II.

USDA Pesticide Data

Survey data to demonstrate time trends in agricultural pesticide use are scarce. The Economic Research Service (ERS), U.S. Department of Agriculture (USDA), conducted five national surveys in 1964, 1966, 1971, 1976, and 1982 (table 1). These surveys provided estimates statistically significant at national and regional levels. As a result of budgetary constraints, the area and crops surveyed in successive studies have been reduced. In 1964, 1966, and 1971, pesticide use data were collected for field crops, fruits, vegetables, and livestock in all States. The 1976 survey excluded fruits and vegetables. The 1982 survey collected pesticide use data for major field crops (corn, soybeans, cotton, wheat, barley, oats, peanuts, tobacco, alfalfa, and hay) only, and pest

Table 1--ERS pesticide use surveys

Item	1964	1966	1971	1976	1977	1978	1979	1980	1982 1/	1984	1985	1986	1987
Area coverage:													
National	X	X	X	X					X				
Regional	X	X	X	X	X	X	X	X	X		X	X	X
State					X		X	X		X	X	X	X
Commodities:													
Corn	X	X	X	X				X	X	X	X	X	X
Cotton	X	X	X	X			X		X		X		X
Wheat	X	X	X	X					X	X	X	X	X
Sorghum	X	X	X	X				X	X				X
Rice	X	X	X	X					X				
Other grains	X	X	X	X					X				
Soybeans	X	X	X	X				X	X	X	X	X	X
Tobacco	X	X	X	X					X				
Peanuts	X	X	X	X					X				
Other field crops	X	X	X										
Potatoes	X	X	X				X						
Other vegetables	X	X	X				X						
Deciduous fruit	X	X	X			X							
Citrus	X	X	X		X								
Other fruit	X	X	X				X						
Livestock	X	X	X	X					X 2/				
Pesticide use information:													
Pounds of active ingredient	X	X	X	X	X	X	X	X	X				
Application rate					X	X	X	X	X				
Acres treated	X	X	X	X	X	X	X	X	X	X	X	X	X
Number of treatments					X	X	X	X	X				
Acre treatments					X	X	X	X	X				
Pesticide expenditures 3/	X	X	X						X				

1/ Excludes Alaska, California, Colorado, Connecticut, Hawaii, Maine, Massachusetts, New Hampshire, New Jersey, New Mexico, Nevada, Oregon, Rhode Island, Utah, Vermont, West Virginia, and Wyoming.
2/ Expenditures only.
3/ Excludes expenditure data from Farm Costs and Returns Surveys.

control expenditures for livestock, but was restricted to 33 States.2/ Because of budgetary and other reasons, no national surveys have been conducted since 1982.

ERS has also surveyed individual crops: citrus in 1977; deciduous fruit in 1978; vegetables, potatoes, grapes (New York and Pennsylvania), and cotton in 1979; and corn, sorghum, and soybeans in 1980. Pesticide use estimates, excluding quantities of active ingredient, have been collected for corn, sorghum (1987 only), soybeans, cotton (excluding insecticides), and wheat for 1984-87. Barley, oats, peanuts, tobacco, and potatoes were surveyed in 1987, but those data are not yet summarized. Many of the individual crop surveys provide statistically significant estimates for major producing States.

The quantities of insecticides, herbicides, fungicides, and other pesticides used on selected crops estimated from these surveys are summarized in appendix tables 1-5, and regional data from the five ERS national surveys are summarized in appendix tables 6-25.

The absence of fruit and vegetable data since 1979, however, is a major shortcoming. A major portion of these crops was treated with fungicides and insecticides, as shown in the 1964, 1966, and 1971 national surveys and the 1978 and 1979 fruit surveys (app. tables 1 and 3). Analyzing the possible health, safety, and environmental problems associated with pesticide use in fruit and vegetable production is very difficult because of the data deficiencies. When attempts are made to assess environmental, health, and safety considerations, the required assumptions about use affect the estimates of both risks and benefits (54). Unrealistic assumptions about use may invalidate the results and subsequent policy recommendations.

The most common measure of pesticide use is total quantity (in pounds) of active ingredient (a.i.). (Active ingredient is the material in a pesticide product that controls pests. The remaining materials, the bulk of most pesticide products, are inert ingredients.) Total quantity is a function of the acreage treated with a pesticide one or more times, the number of treatments per treated acre, and the pesticide application rate per treatment measured in pounds of active ingredient. However, not all pesticides are applied at the same rate. Many new pesticides are applied at much lower rates than those introduced 20-30 years ago. Total quantity, therefore, could indicate a reduction in pesticide use when the number of acres treated and number of applications per acre are not actually decreasing. Also, one cannot draw any conclusions about environmental or health hazards based on total pesticide quantity without knowing the toxicity of, quantity of, and exposure to individual active ingredients.

Acreage treated is the area treated with a pesticide or group of pesticides one or more times. Because an acre can be treated with more than one pesticide, the acreage treated with one pesticide or group of pesticides cannot be added to the acreage treated with another. Acre-treatments are the acreage treated times the number of applications per acre. These numbers can be added, but have only been collected since the late 1970's.

2/ Alaska, California, Colorado, Connecticut, Hawaii, Maine, Massachusetts, New Hampshire, New Jersey, New Mexico, Nevada, Oregon, Rhode Island, Utah, Vermont, West Virginia, and Wyoming were not surveyed in 1982.

ERS has not collected total quantity and application rate per acre data since the 1982 survey, making it impossible to study the effects that recent economic conditions have had upon those variables.

Other Data Sources

USDA is one of the few sources of publicly available agricultural pesticide use survey data for the United States, but there are other data sources (29). The Environmental Protection Agency (EPA) annually publishes estimates of pesticide sales and use and occasionally conducts State surveys. EPA's estimates of sales and use are based upon National Agricultural Chemical Association surveys, EPA staff estimates, USDA estimates for some years, and proprietary sources. EPA's estimates are not necessarily based on statistically based surveys. The Bureau of the Census publishes estimates of broad classes of pesticides (such as insecticides and herbicides) and also conducts special surveys for selected States.

Few States publish pesticide use data on a regular basis. Twenty-three States have published reports through the National Agricultural Pesticide Impact Assessment Program, but only six have completed reports since 1982. Another six States are preparing them for 1986 or 1987. Agencies in Arkansas, California, Maryland, Nevada, New Hampshire, and Vermont regularly publish reports on the quantities of restricted-use or commercially applied materials.

Resources for the Future uses secondary sources, assumes that average-use patterns hold across a State, and develops county-level estimates of pesticide quantities proportional to crop acreage in the county. There are also proprietary sources of pesticide data: Doane Marketing Services, Maritz, Technomics, individual chemical manufacturers, and the National Agricultural Chemical Association.

Aggregate Pesticide Use

Three data points are available from USDA sources to illustrate total U.S. pesticide use on a consistent basis: 1964, 1966, and 1971. The 1976 survey deleted fruits and vegetables, and the 1982 survey collected data only on major crops in 33 States. Total pesticide use (excluding sulfur and petroleum) grew from 305 million pounds of active ingredient (a.i.) in 1964 to 479 million pounds a.i. in 1971 (fig. 3 and table 2). The use for crops deleted from the 1976 survey was projected from previous surveys and trends so that total crop use was estimated to be 651 million pounds a.i. for that year. Growth in total pesticide use during that period is primarily from pesticide use on major field crops, because pesticide use on other crops and livestock was relatively small and stable in comparison. However, pesticide use per acre on some specialty or "minor use" crops is very high compared with major crops.

Pesticide use on major field crops grew from 225 million pounds a.i. in 1964 to 548 million pounds a.i. in 1976 and to 558 million pounds by 1982 a.i. (fig. 4 and table 2). Corn and soybeans account for a large portion of the increase in pesticide quantity used on major field crops. The total quantity used on these two crops grew from 50 million pounds a.i. (22 percent of total quantity) in 1964 to 412 million pounds a.i. (74 percent of total quantity) in 1982 (app. table 5). Increased use of pesticides on the major field crops since 1964 is largely a result of increased herbicide use, from 71 million pounds a.i. in 1964 to 456

Figure 3
Total quantity of agricultural pesticides

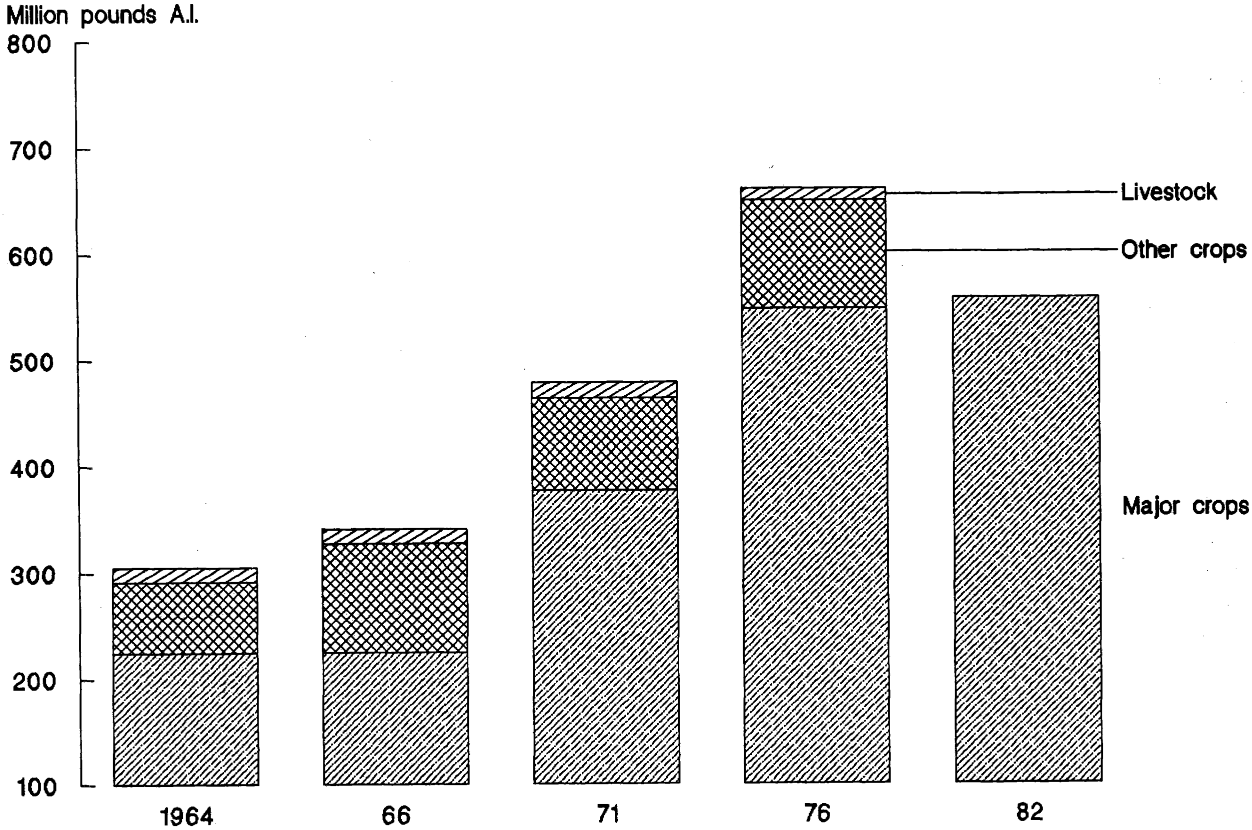


Figure 4
Pesticide quantity used on major crops

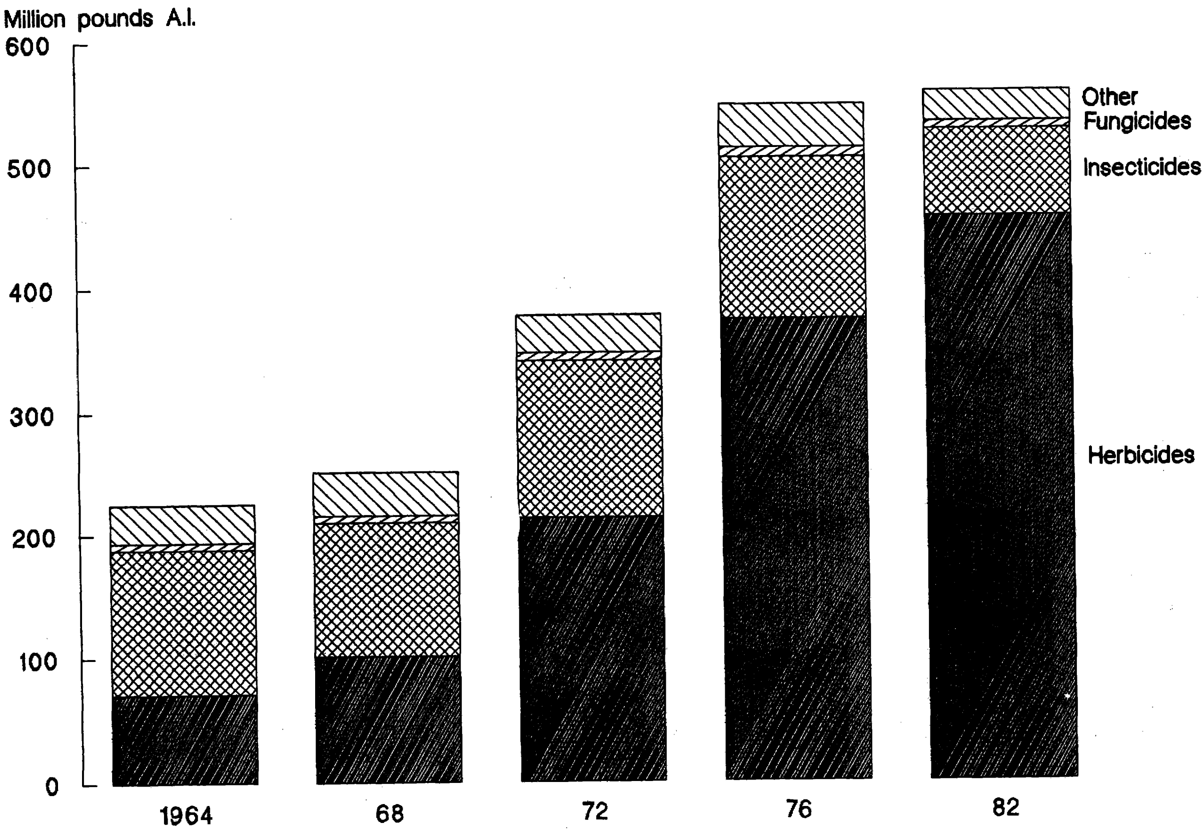


Table 2--Total agricultural pesticide use 1/

Year	Major crops 2/	Other crops	Livestock	Total
		Million pounds a.i.		
1964	224.7	66.7	13.7	305.1
1966	251.1	77.0 3/	12.5	340.6
1971	377.2	86.5 3/	14.8	478.5
1976	547.6	102.2 4/	10.8	660.6
1982	557.7	NA	NA	NA

NA = Not available.
1/ Active ingredients excluding sulfur and petroleum.
2/ Cotton, corn, soybeans, sorghum, rice, tobacco, peanuts, wheat, other small grains, alfalfa, other hay, and pasture.
3/ Includes nursery crops and summer fallow.
4/ Estimated from 1971 survey results and crop use trends (20).

million pounds a.i. in 1982 (table 3). Insecticide use increased from 117 million pounds a.i. in 1964 to 129 million pounds a.i. in 1971, increased slightly to 130 million pounds a.i. in 1976, and then fell dramatically to 71 million pounds a.i. in 1982 (table 3). The use of fungicides and other pesticides was relatively stable between 1964 and 1982, increasing from 38 million pounds a.i. in 1964 to 43 million pounds in 1976 and decreasing to 31 million pounds a.i. in 1982.

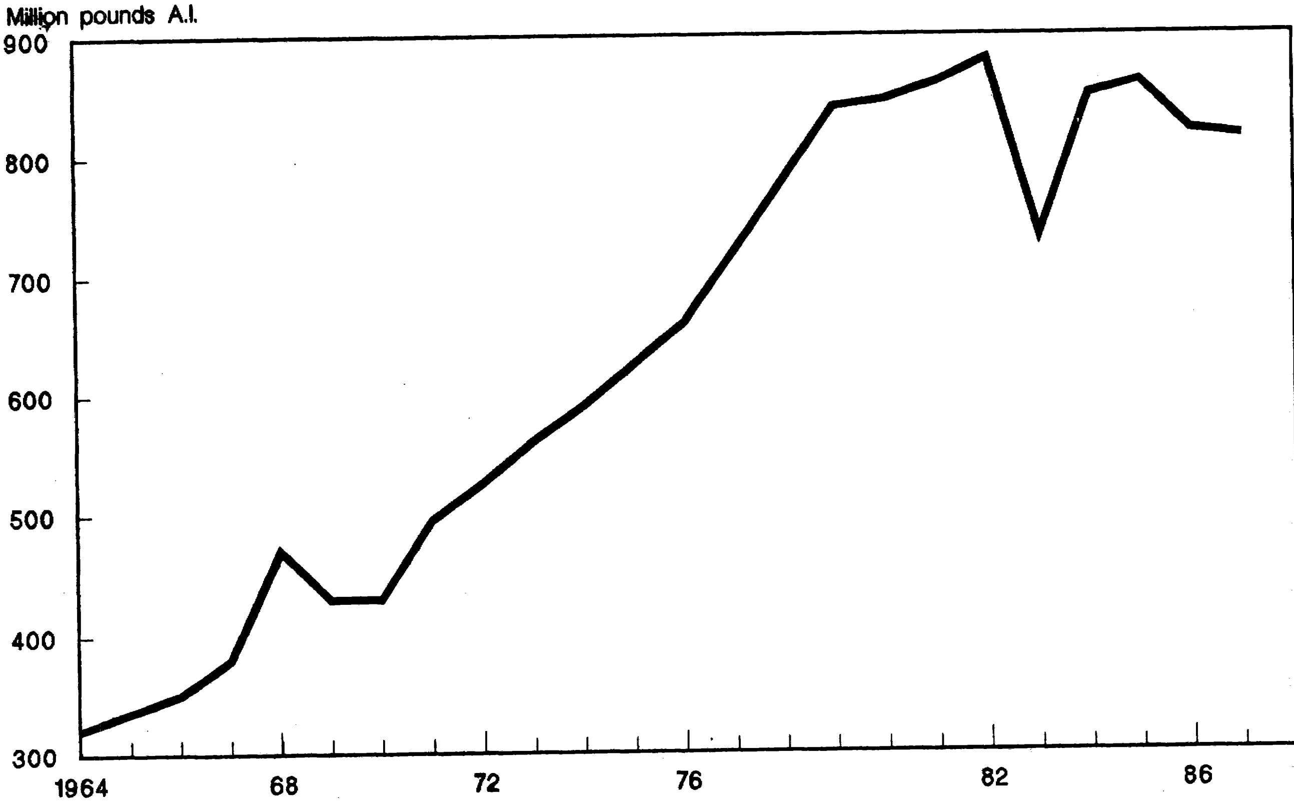
EPA estimates of agricultural pesticide use from 1964 to 1986 show rapid growth in the 1960's and 1970's (fig. 5, 86). Beginning in 1979, growth slowed but continued until 1982. After that, lower use reflected reduced crop acreage resulting from low crop prices, acreage diversion, and land retirement programs. The effect of the 1983 payment-in-kind acreage diversions is especially noticeable. Pesticide quantity increased from 320 million pounds a.i. in 1964 to 880 million pounds a.i. in 1982, but fell to 820 million pounds a.i. in 1986. The EPA estimates of 1964, 1966, 1971, and 1976 compare favorably with the USDA survey estimates for those years. However, the EPA estimate of 880 million pounds a.i. for 1982 is much greater than the USDA estimate of 557 million pounds a.i., reflecting the restricted crop and area coverage by the 1982 USDA survey.

Increasing pesticide use embodies two important trends: (1) use for individual crops and (2) development and adoption of new pesticide compounds. The rate at which new products are adopted can be attributed to their cost-effectiveness, pest resistance problems with older products, and pesticide regulatory activity.

Insecticide Use

During the 1950's, insecticide use, as measured by the percentage of acreage treated, was well established on a number of high-value crops especially susceptible to insect damage, including cotton, tobacco, potatoes, vegetables, and fruits and nuts (table 4). By the 1960's, the percentage of the acreage of these crops treated with insecticides stabilized. Unusual insect infestations or

Figure 5
Agricultural pesticide use



Source: (86).

Table 3--Pesticide use on major crops 1/

Year	Herbicides	Insecticides	Fungicides	Other	Total
			Million pounds a.i.		
1964	70.5	116.7	5.8	31.7	224.7
1966	101.2	108.3	6.0	35.7	251.1
1971	213.1	127.9	6.4	29.8	377.2
1976	373.9	130.3	8.1	35.3	547.6
1982	455.6	71.2	6.6	24.3	557.7

1/ Active ingredients excluding sulfur and petroleum. Major crops are cotton, corn, soybeans, sorghum, rice, tobacco, peanuts, wheat, other small grains, alfalfa, other hay, and pasture.

weather could require the expansion of treated area and the amount of pesticide used.

Insecticide markets for several major field crops developed later than for the crops discussed above. Corn is a dramatic example. About 10 percent of corn acreage was treated during the mid-1950's, but that share grew rapidly to 33 percent by 1966, and appears to have stabilized at 35-45 percent of planted acres

Table 4--Share of crop acres treated with insecticides

Year	Corn	Cotton	Soybeans	Wheat	Sorghum	Fruits and nuts	Potatoes
				Percent			
1952	1	48	NA	NA	NA	82	75
1958	6	66	NA	NA	NA	81	80
1966	33	54	NA	NA	NA	87	91
1971	35	61	8	7	39	90	84
1976	38	60	7	14	27	NA	NA
1979	NA	48	NA	NA	NA	NA	94
1980	43	NA	11	NA	24	NA	NA
1982	37	36	12	3	26	NA	NA
1984	42	63	8	NA	NA	NA	NA
1985	45	65	7	5	NA	NA	NA
1986	41	NA	4	7	NA	NA	NA
1987	41	61	3	7	17	NA	NA
1988	35	61	8	4	NA	NA	NA

Year	Vegetables	Tobacco	Peanuts	Rice	Other grains	Alfalfa	Other hay
				Percent			
1952	61	47	NA	NA	NA	NA	NA
1958	74	58	NA	NA	NA	NA	NA
1966	58	82	NA	NA	NA	NA	NA
1971	58	77	87	35	3	8	2
1976	NA	76	55	11	5	13	2
1979	74	NA	NA	NA	NA	NA	NA
1982	NA	85	48	16	1	7	1

NA = Not available.

Sources: (19, 74, 77).

since 1975 (fig. 6). The primary use is for soil insects on continuous corn rotations. Soybeans (for which we have no data before 1971) follow a similar but less dramatic pattern (fig. 7). However, the percentage of soybean acreage treated appears to have fallen since 1982, perhaps because of decreased pest infestations in many regions.

Cotton, corn, and soybeans accounted for 82 percent of total quantity of insecticide use on major field crops in 1982. The decline in major crop insecticide use between 1976 and 1982 occurred primarily on cotton, where quantity fell from 73 million pounds a.i. in 1971 to 64 million pounds a.i. in

Figure 6
Share of corn acreage treated with pesticides

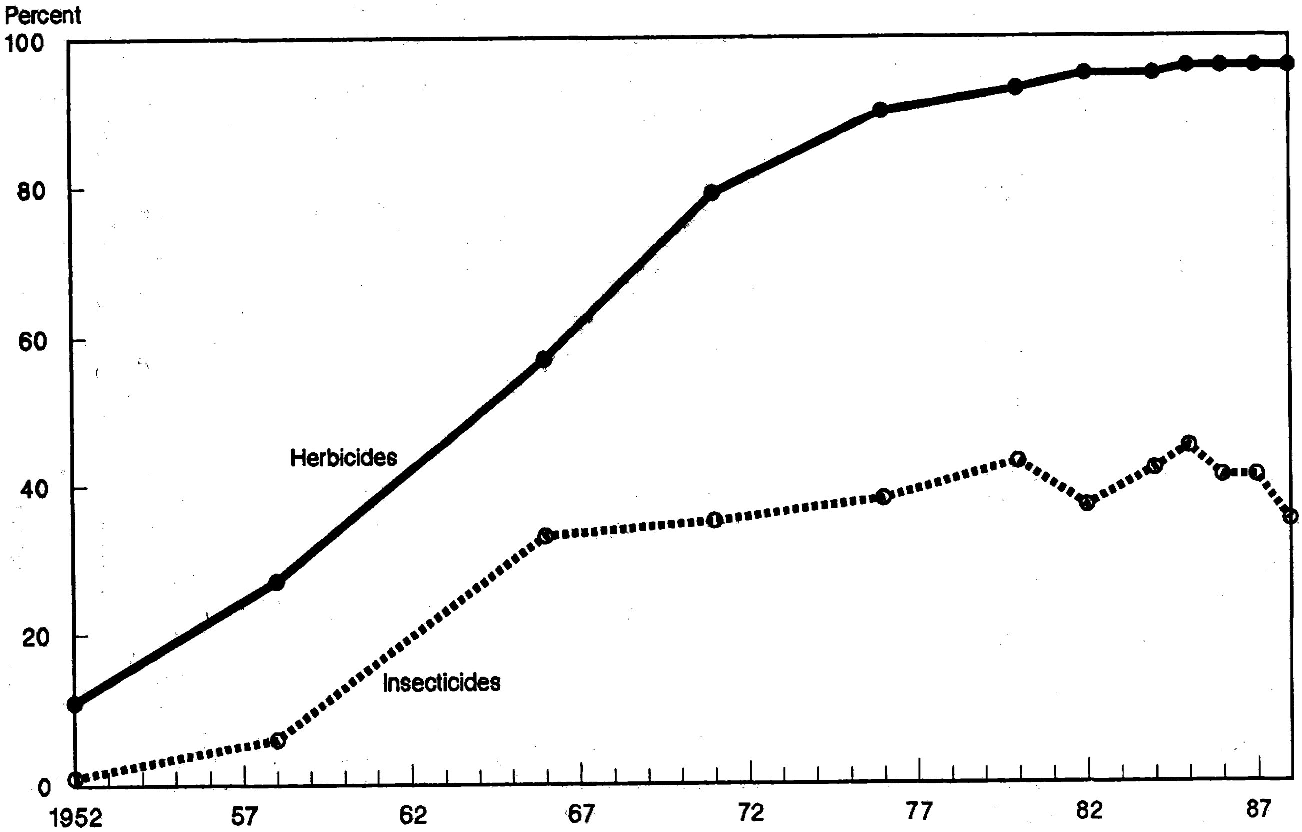
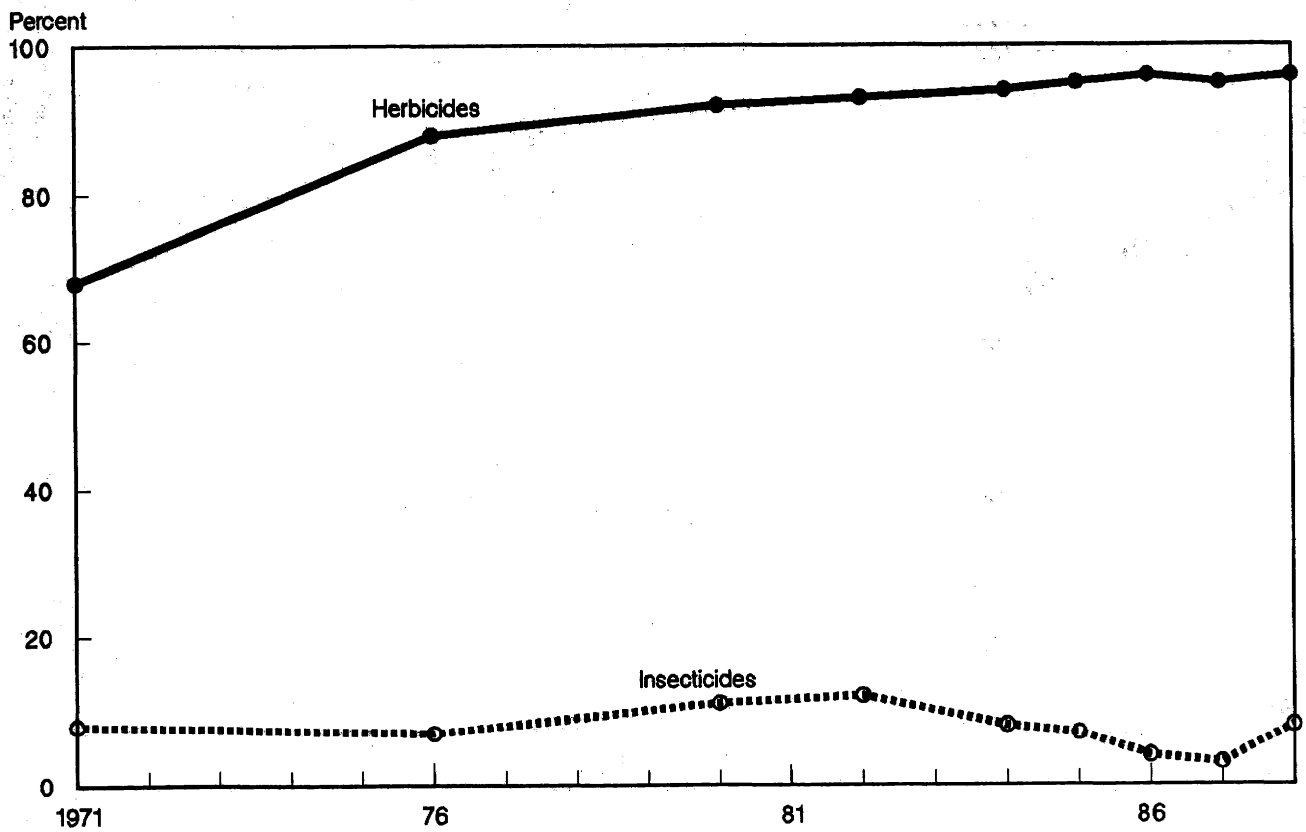


Figure 7
Share of soybean acreage treated with pesticides



1976, and to 17 million pounds a.i. in 1982 and 1984 (table 5 and fig. 8).3/ Corn and soybean insecticide quantity increased from 21 million pounds a.i. in 1964 to 41 million pounds a.i. in 1982. The 30 million pounds a.i. of

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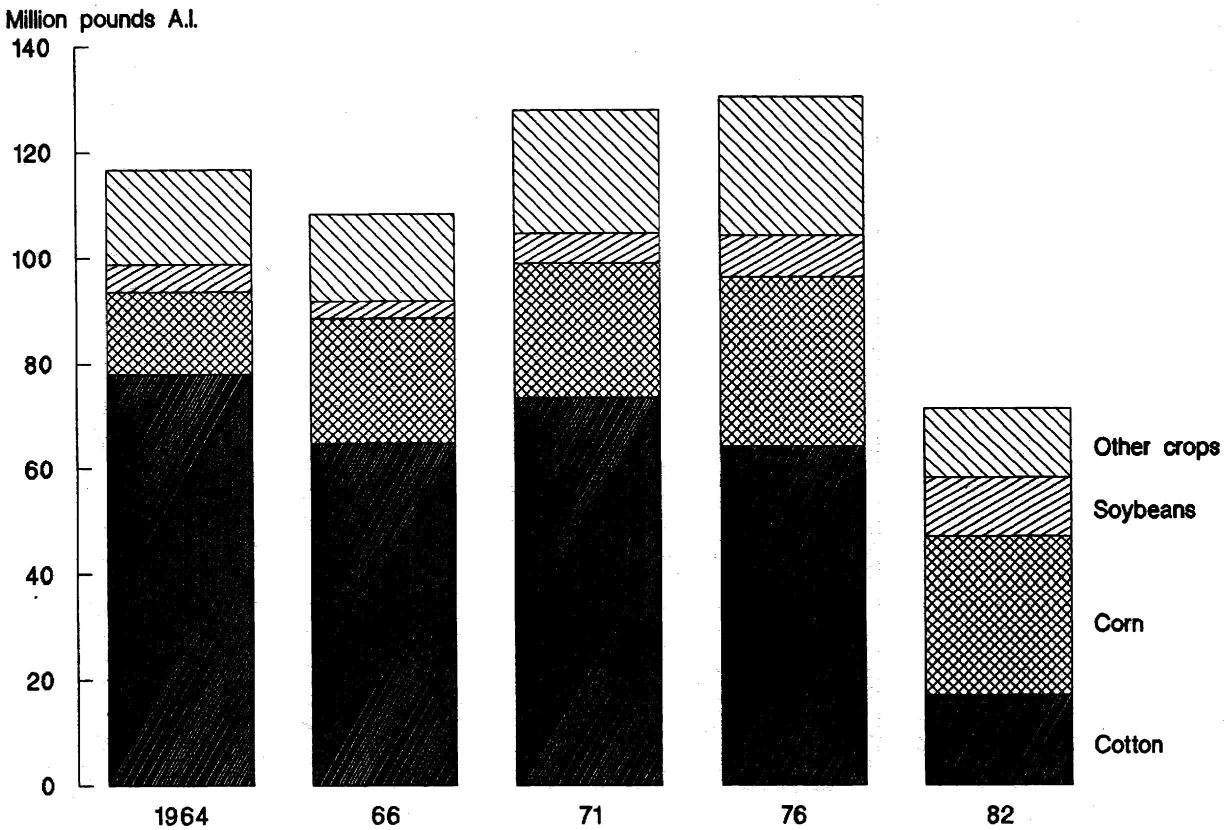
3/ The 1984 estimate is from the chlordimeform assessment (78).

Table 5--Insecticide use on major crops 1/

Crop	1964	1966	1971	1976	1982
			Million pounds a.i.		
Cotton	78.0	64.9	73.4	64.1	16.9
Corn	15.7	23.6	25.5	32.0	30.1
Soybeans	5.0	3.2	5.6	7.9	11.1
Other crops	18.0	16.5	23.4	26.3	13.1
Total	116.7	108.2	127.9	130.3	71.2

1/ Active ingredients excluding petroleum. Major crops are cotton, corn, soybeans, sorghum, rice, tobacco, peanuts, wheat, other small grains, alfalfa, other hay, and pasture.

Figure 8
Insecticides used on major crops



insecticides applied to corn in 1982, in fact, surpassed the amount used in cotton production (17 million pounds a.i.) for the first time.

The decline in insecticide use between 1976 and 1982 largely reflects the changing composition of compounds used. Organophosphates, carbamates, and pyrethroids displaced the organochlorines (also known as chlorinated hydrocarbons), which lost their effectiveness against agricultural pests because of pest resistance (table 6 and fig. 9).4/ Pesticide regulatory actions also limited organochlorine use after the discovery of their persistence in the environment reduced or eliminated their markets in the 1970's and 1980's. Organochlorine use fell steadily from 70 percent of synthetic organic pesticides (by pounds a.i.) in 1966 to only 6 percent in 1982. Organophosphate use grew from about 20 percent of the total in 1966 to almost 70 percent in 1982. The growth of carbamates has been less dramatic, perhaps because of resistance in cotton insects and the effectiveness of other insecticides (1).

The appearance of pyrethroids in the 1982 pesticide use estimates is particularly significant. This group of chemicals was introduced in 1977 and accounted for about 4 percent of insecticide quantity used in 1982. Due to their low rates of application, pyrethroids are applied to a much greater percentage of acres treated than their share of total quantity, suggesting that much of the decline in cotton insecticide use is due to increased pyrethroid use. Pyrethroids are widely used to control Heliothis spp. (cotton bollworms and tobacco budworms), replacing organochlorines and organophosphates.

Over the years, the composition of cotton insecticide use shows a pattern similar to that for major crops (tables 6 and 7 and figs. 9 and 10). Thus, cotton insecticide use fell from 5-6 pounds a.i. per crop-acre before 1977 to about 1.6 pounds a.i. after 1977, even though the percentage of acres treated has generally varied between 48 and 65 percent with no measurable trend (figs. 11 and 12 and table 4). However, some of the decline in cotton insecticide use in 1982 may have resulted from pest or weather conditions.

4/ See table 8 for a list of important pesticides in each class.

Table 6--Shares of insecticide classes on major crops 1/

Year	Organo-chlorines	Organo-phosphates	Carbamates	Pyrethroids	Other
			Percent		
1964	70	20	8	0	2
1966	70	22	7	0	1
1971	45	39	14	0	2
1976	29	49	19	0	3
1982	6	67	18	4	5

1/ Active ingredients excluding petroleum. Major crops are cotton, corn, soybeans, sorghum, rice, tobacco, peanuts, wheat, other small grains, alfalfa, other hay, and pasture.

Table 7--Shares of insecticide types used on cotton 1/

Year	Organo-chlorines	Organo-phosphates	Carbamates	Pyrethroids	Other
			Percent		
1964	74	20	6	0	0
1966	77	21	2	0	0
1971	58	40	2	0	0
1976	43	48	2	0	7
1979	11	64	10	8	7
1982	7	71	9	12	1
1984 2/	13	61	11	8	7

1/ Active ingredients excluding petroleum.
2/ Estimates from the chlordimeform assessment (78).

Table 8--Some pesticides in major classes

Insecticides:

Organochlorines: aldrin, chlordane, dieldrin, DDT, methoxychlor, toxaphene

Organophosphates: fonofos, isofenphos, malathion, methyl parathion, parathion, phorate, terbufos

Carbamates: aldicarb, carbaryl, carbofuran, methomyl

Pyrethroids: fenvalerate, cypermethrin, permethrin

Herbicides:

Amides: alachlor, metolachlor, propachlor

Anilines: oryzalin, pendimethalin, trifluralin

Carbamates: butylate, EPTC

Nitrophenols: dinoseb

Phenoxys: 2,4-D, 2,4-DB, 2,4,5-T, MCPA

Triazines: atrazine, cyanazine, metribuzin, propazine, simazine

Figure 9
Proportion of insecticide types used on major crops

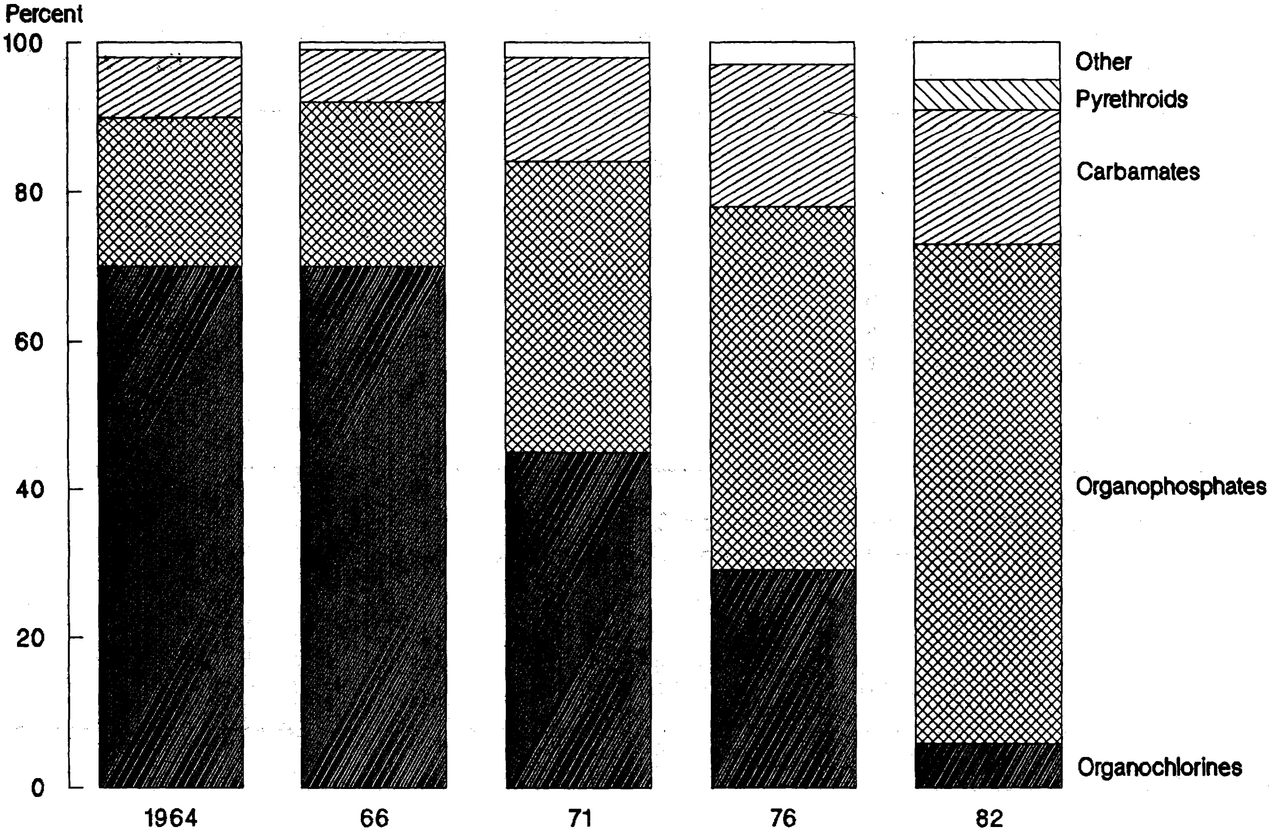


Figure 10
Proportion of insecticide types used on cotton

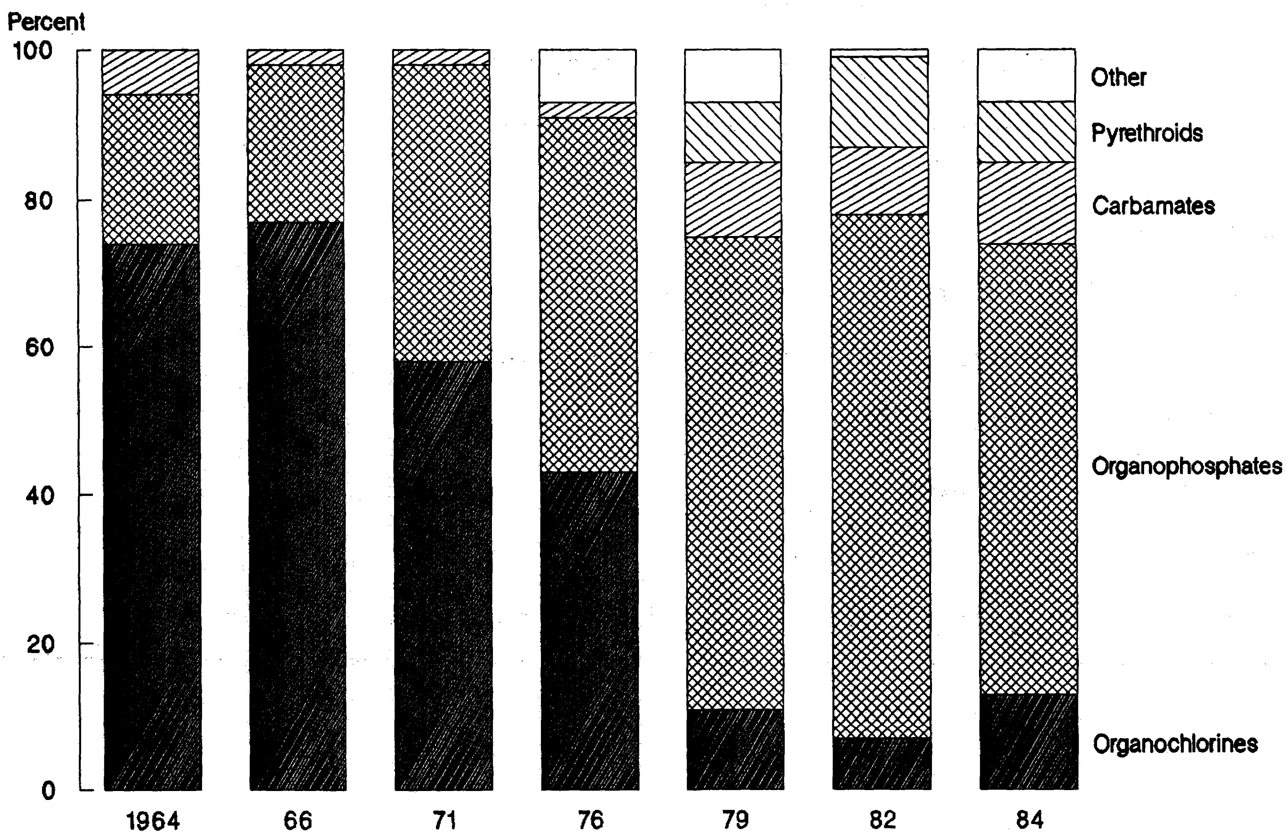


Figure 11
Insecticides used on cotton

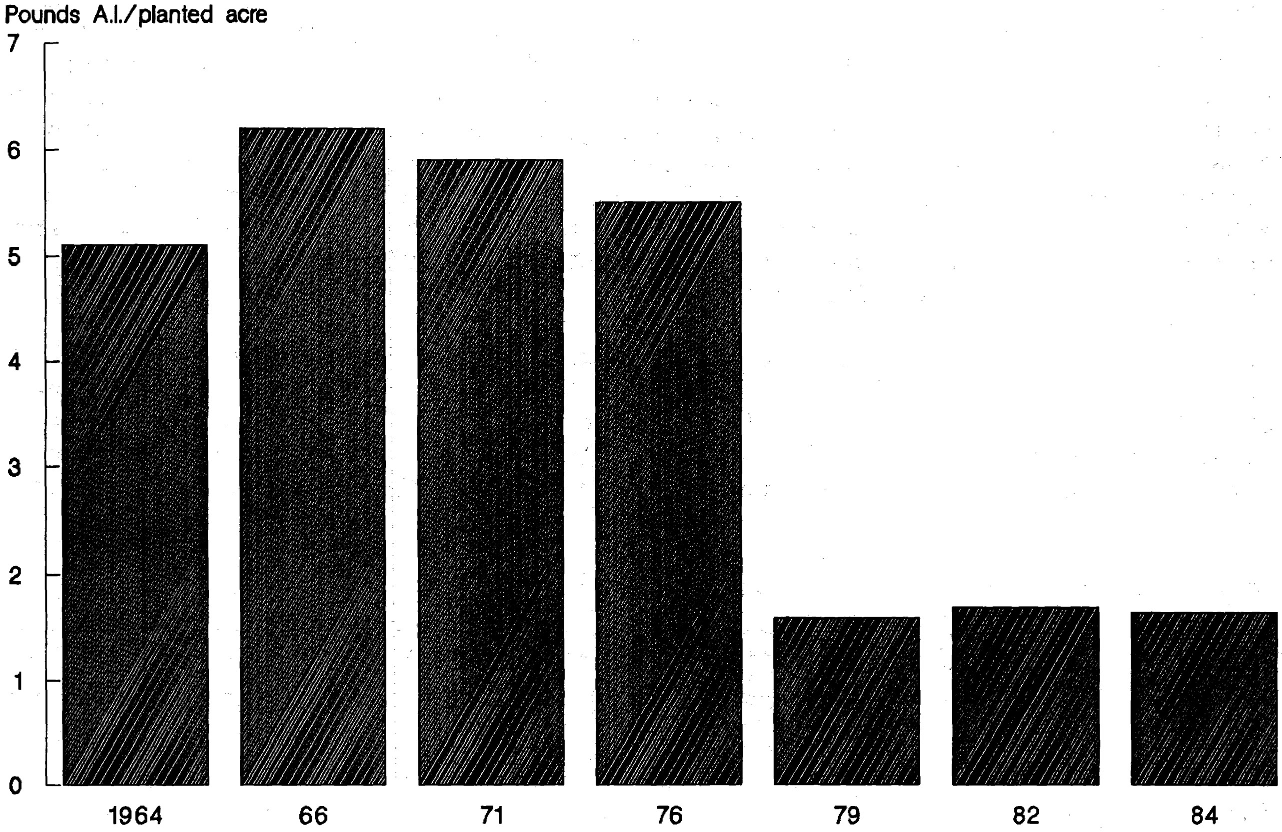
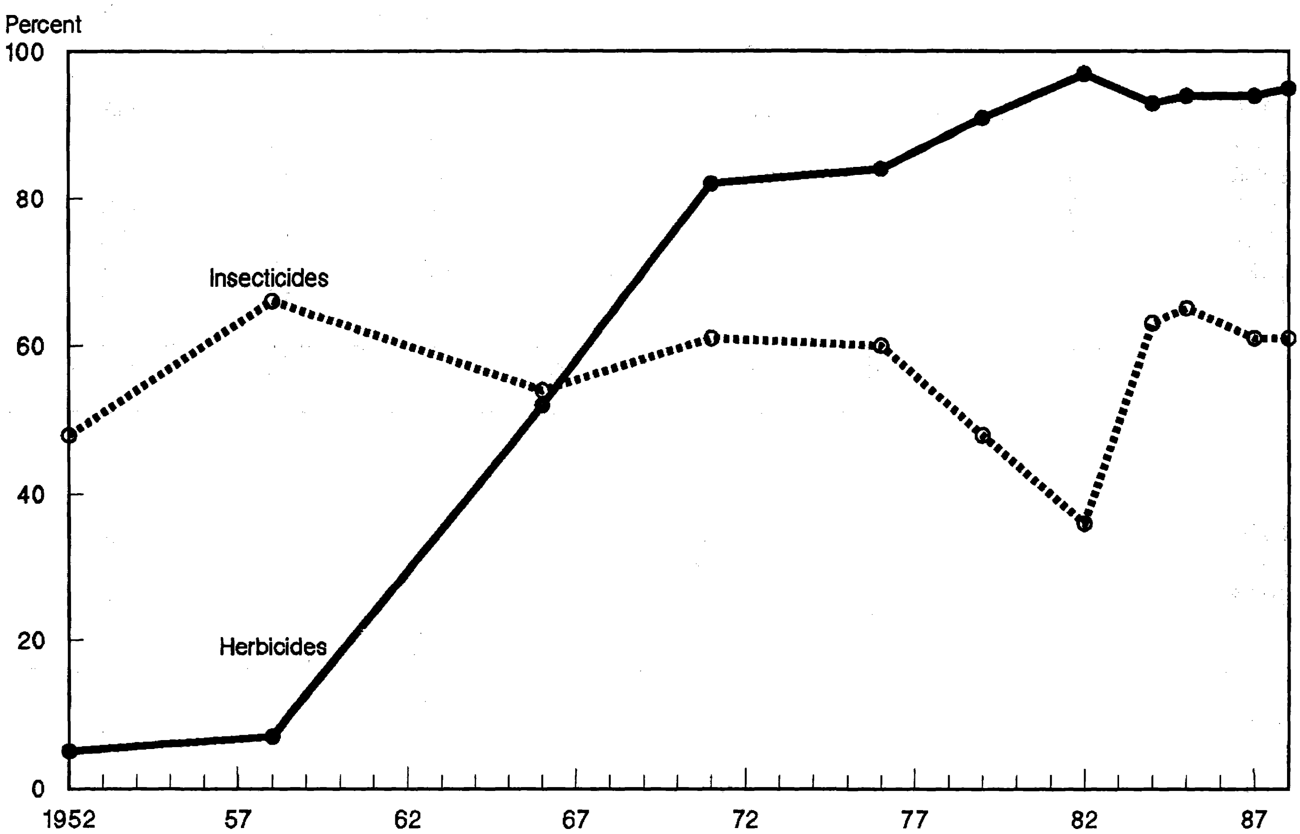


Figure 12
Share of cotton acreage treated with pesticides



Herbicides

Herbicide use grew more and stabilized later than insecticide use. The growth in the use of corn, cotton, and wheat herbicides began during the 1950's (figs. 6, 12-14, and table 9). Less than 10 percent of the acreage of these crops was treated with herbicides in 1952. Herbicide use on corn, cotton, and soybeans (no pre-1971 soybean data are available; see fig. 7) appears to have stabilized at 90-96 percent of acres planted around 1980. Wheat herbicide use is not so clearly defined and may, in fact, still be growing. Much of the variation in herbicide use in wheat production may reflect the ratio between spring and winter wheat acreage, because a much greater percentage of spring wheat than winter wheat acreage is treated with herbicides.

Corn and soybeans account for the major portion of herbicide use on major field crops (fig. 14 and table 10). Herbicide quantity used on these two crops grew from 30 million pounds a.i. in 1964 (42 percent of all herbicide used) to 370 million pounds a.i. in 1982 (81 percent). The quantity of herbicides used on other crops has also grown, but not as dramatically. For example, the quantity

Table 9--Share of crop acres treated with herbicides

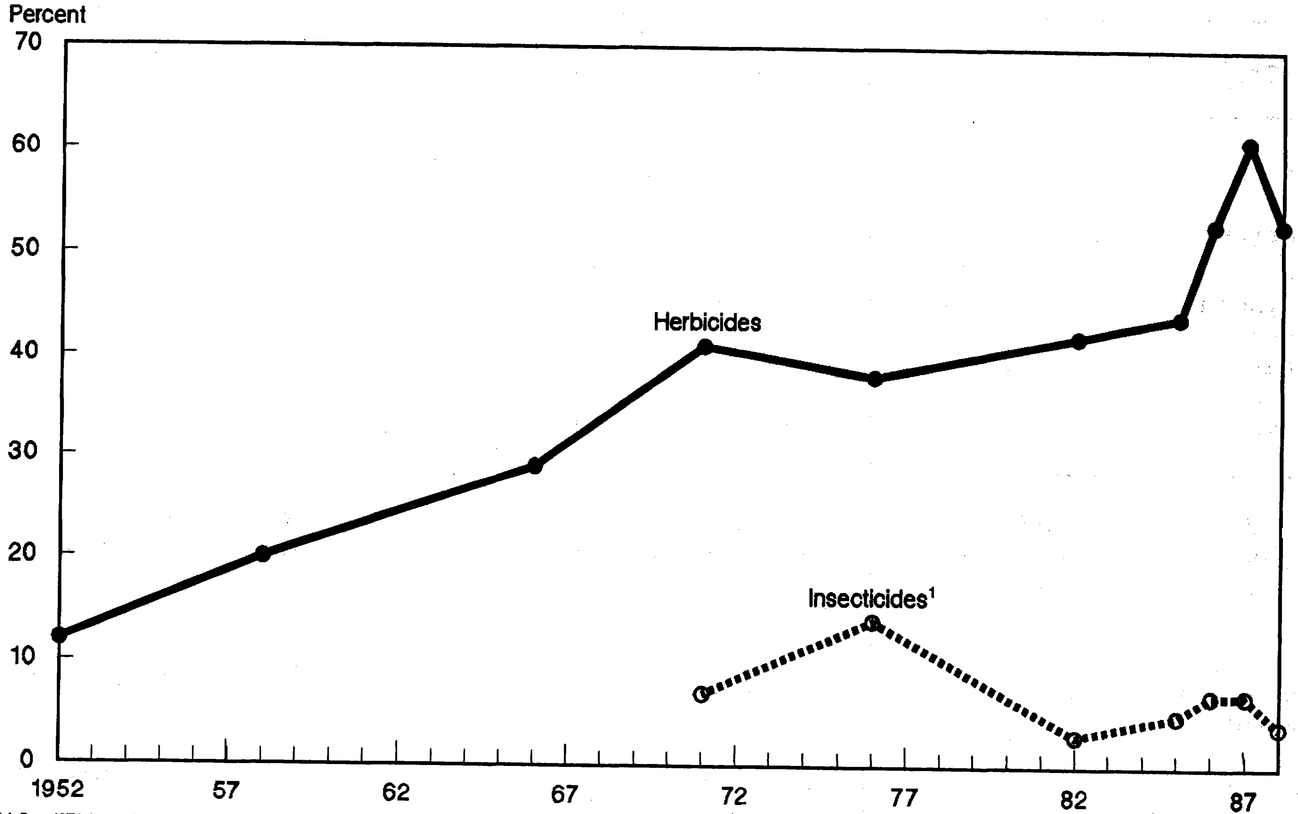
Year	Corn	Cotton	Soybeans	Wheat	Sorghum	Potatoes	Vegetables
				Percent			
1952	11	5	NA	12	NA	NA	NA
1958	27	7	NA	20	NA	NA	NA
1966	57	52	NA	29	NA	NA	NA
1971	79	82	68	41	46	NA	NA
1976	90	84	88	38	51	NA	NA
1979	NA	91	NA	NA	NA	73	84
1980	93	NA	92	NA	61	NA	NA
1982	95	97	93	42	59	NA	NA
1984	95	93	94	NA	NA	NA	NA
1985	96	94	95	44	NA	NA	NA
1986	96	NA	96	53	NA	NA	NA
1987	96	94	95	61	82	NA	NA
1988	96	95	96	53	NA	NA	NA

	Tobacco	Rice	Peanuts	Other grains	Alfalfa	Other hay
				Percent		
1971	7	95	92	31	1	2
1976	55	83	93	35	3	2
1982	71	98	93	45	1	3

NA = Not available.

Sources: (19, 74, 77).

Figure 13
Share of wheat acreage treated with pesticides



1/ Pre-1971 insecticide use data are unavailable.

Figure 14
Herbicides used on major crops

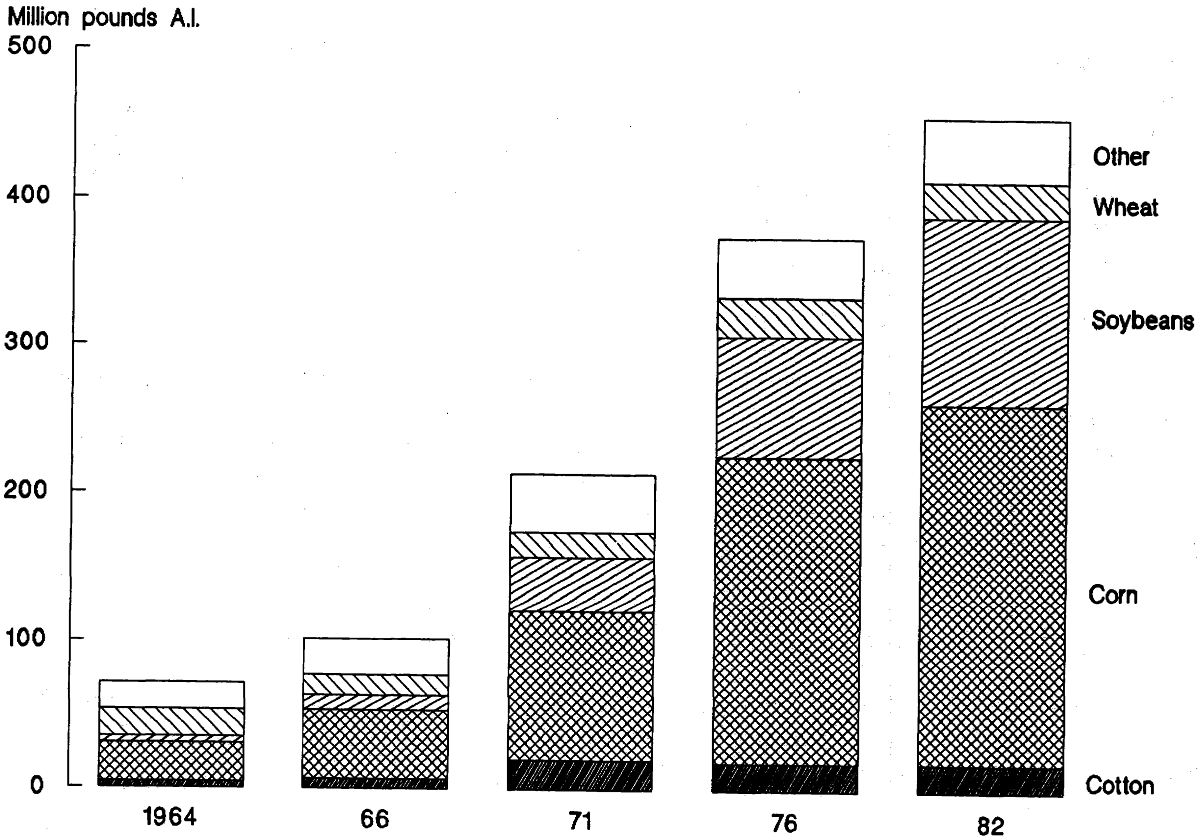


Table 10--Herbicide use on major crops 1/

Crop	1964	1966	1971	1976	1982
			Million pounds a.i.		
Cotton	4.6	6.5	19.6	18.3	18.3
Corn	25.5	46.0	101.1	207.1	243.4
Soybeans	4.2	10.4	36.5	81.1	127.0
Wheat and small grains	18.3	13.2	17.0	27.4	24.0
Other crops	17.9	25.1	38.9	40.0	42.9
Total	70.5	101.1	213.1	373.9	455.6

1/ Active ingredients excluding petroleum. Major crops are cotton, corn, soybeans, sorghum, rice, tobacco, peanuts, wheat, other small grains, alfalfa, other hay, and pasture.

of cotton herbicides increased from 5 million pounds a.i. in 1964 to 18 million pounds a.i. in 1982.

The patterns of herbicide compounds that farmers use have also changed (table 11 and fig. 15). Phenoxy use fell from about 45 percent of total quantity of herbicides used in 1964 to about 5 percent in 1982. That percentage decline is somewhat deceptive. Annual phenoxy use was 30-42 million pounds a.i. during 1964-76 with no particular trend, before falling to 26 million pounds a.i. in 1982. For many years, the phenoxys' falling share was due to the growth in use of other herbicides. During this time, the quantities of amides, triazines, nitrophenols, carbamates, and dinitroanilines have all grown significantly. The nitrophenol compounds have held a significant share of the market, but the primary compound, dinoseb, was the subject of an EPA emergency suspension in 1986. An important new trend is the increasing use of sulfonylurea herbicides, applied at low rates per acre, on wheat.

Regional Pesticide Use on Major Crops

Pesticide use varies by region because pest problems, crop acreages, and the mix of crops grown vary geographically. The Southeast, Appalachia, and Delta generally have greater insect and disease problems than other areas of the United States. (See table 12 for a definition of regions.) Regional pesticide use trends are a function of the trends in regional crop production, pesticide use trends for individual crops as discussed above, and pest problems. Table 13 summarizes regional quantities of insecticides, herbicides, fungicides, and other pesticides used on major crops for the five ERS/USDA national pesticide surveys. Appendix tables 6-25 present regional estimates for individual crops.

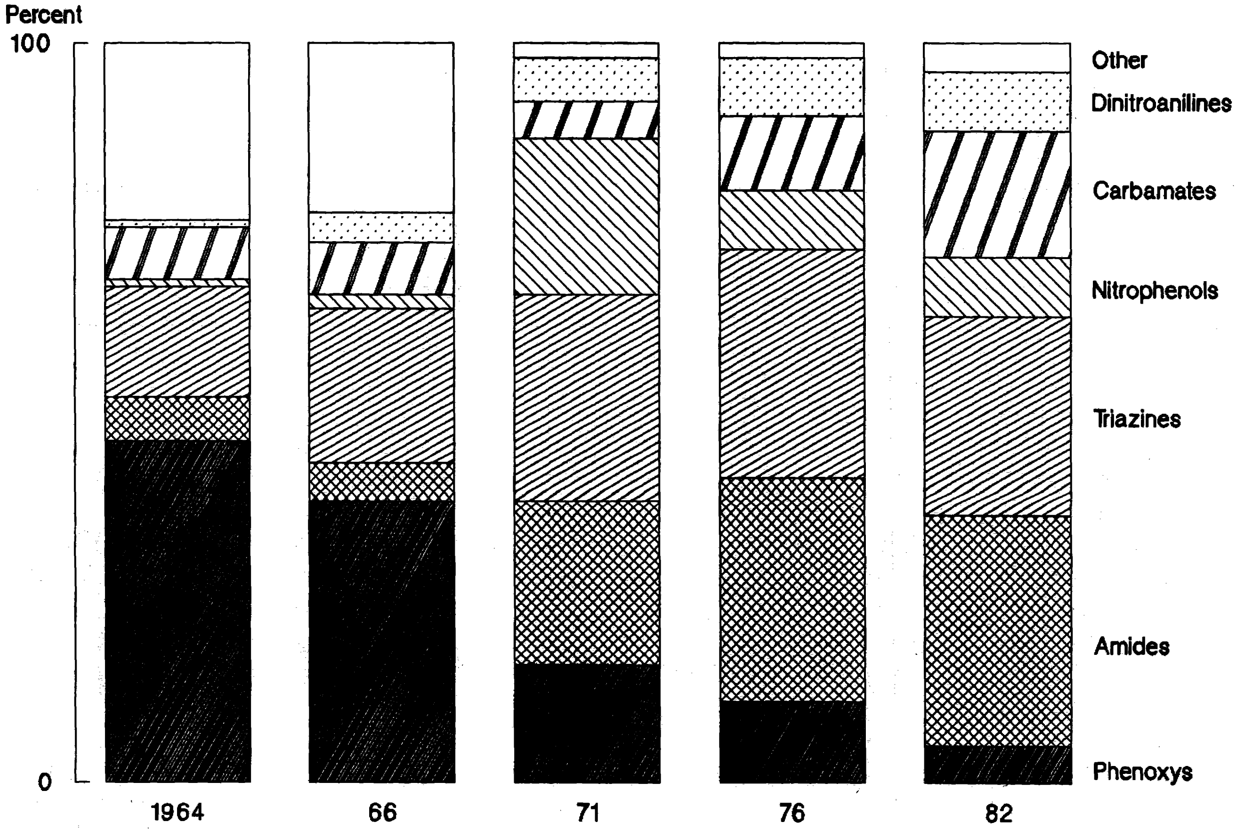
The Southeast and Delta have historically applied the greatest quantity (pounds of active ingredient) of insecticides on major crops. However, these regions have relatively severe insect problems and grow crops susceptible to insect damage such as cotton, peanuts, and tobacco. The Corn Belt and Southern Plains have generally been the third or fourth leading users of insecticides. Because

Table 11--Proportions of herbicide classes used on major crops 1/

Year	Phenoxys	Amides	Triazines	Nitro-phenols	Carbamates	Anilines	Other
				Percent			
1964	46	6	15	1	7	1	24
1966	38	5	21	2	7	4	23
1971	16	22	28	21	5	6	2
1976	11	30	31	8	10	8	2
1982	5	31	27	8	17	8	4

1/ Active ingredients excluding petroleum. Major crops are cotton, corn, soybeans, sorghum, rice, tobacco, peanuts, wheat, other small grains, alfalfa, other hay, and pasture.

Figure 15
Classes of herbicides used on major crops



of cooler climates, these regions usually have less severe insect problems than the Southeast and Delta. Insecticide quantity increased steadily in most regions during 1964-76. From 1971 to 1976, however, insecticide quantity fell in the Southeast, Corn Belt, and Southern Plains.

Table 12--Regions

Northeast:	Connecticut,1/ Delaware,1/ Maine,1/ Maryland, Massachusetts,1/New Jersey,1/ New Hampshire,1/ New York, Pennsylvania, Rhode Island,1/ Vermont 1/
Lake:	Michigan, Minnesota, Wisconsin
Corn Belt:	Illinois, Indiana, Iowa, Missouri, Ohio
Northern Plains:	Kansas, Nebraska, North Dakota, South Dakota
Appalachia:	Kentucky, North Carolina, Tennessee, Virginia, West Virginia 1/
Southeast:	Alabama, Georgia, Florida, South Carolina
Delta:	Arkansas, Louisiana, Mississippi
Southern Plains:	Oklahoma, Texas
Mountain:	Arizona, Colorado,1/ Idaho, Montana, Nevada,1/ New Mexico,1/ Utah,1/ Wyoming 1/
Pacific:	California,1/ Oregon,1/ Washington

1/ Excluded from 1982 survey.

Because of the introduction of pyrethroids in the late 1970's and their lower application rates, the quantity of insecticides used on cotton decreased dramatically in the Southeast, Delta, and Southern Plains. From 1976 to 1982, insecticide quantity used on corn fell slightly, but use on soybeans rose. Thus, the Corn Belt used the greatest quantity of insecticides in 1982, and the Southeast, Delta, and Southern Plains ranked second through fourth. In fact, insecticide quantity rose in the Corn Belt from 1976 to 1982 but fell in all other regions.

The quantity of herbicides used on major crops was the greatest in the Corn Belt for all surveyed years. Use in the Corn Belt grew almost twelvefold from 1964 to 1982, surpassing other regions. That increase was primarily due to increased corn and soybean herbicide use. The Lake States ranked fourth in 1964 but rose to second by 1971 as herbicide quantity grew more than eightfold from 1964 to 1982, with corn and soybeans being the major contributors. The quantity of herbicides used in the Northern Plains grew only about sixfold during 1964-82, because pesticides are not used as much on the large acreages of wheat and other small grains commonplace in the region as on corn and soybeans. Herbicide use in

Table 13--Pesticide active ingredient types used on major crops, by region and year

Item	Northeast	Lake	Corn Belt	Northern Plains	Appa-lachia	South-east	Delta	Southern Plains	Mountain	Pacific
					1,000 pounds					
Herbicides:										
1964	4,653	7,529	16,848	8,949	4,651	2,870	4,802	6,131	8,161	5,842
1966	3,210	10,773	35,074	14,470	5,130	4,595	5,902	7,481	5,800	8,797
1971	5,943	28,699	75,753	27,522	12,319	10,619	24,232	15,015	6,114	6,885
1976	12,867	44,039	155,277	43,219	31,801	18,051	33,921	14,404	8,470	11,829
1982	14,727 1/	62,778	197,894	53,107	34,142 2/	22,884	41,168	17,554	11,315 3/	NA
Insecticides:										
1964	626	1,082	12,725	2,641	11,863	32,093	26,888	21,574	3,045	4,148
1966	1,124	1,732	18,290	4,334	9,060	30,837	21,371	13,881	6,110	1,453
1971	472	3,149	16,288	7,265	8,705	36,109	31,964	17,073	4,209	2,703
1976	2,599	5,201	15,738	11,013	9,549	30,125	33,710	12,944	4,540	4,879
1982	1,915 1/	3,800	17,307	7,784	5,833 2/	13,460	11,567	7,149	2,418 3/	NA
Fungicides:										
1964 4/	339	178	1,042	309	15,742	41,849	61	5,164	409	3,752
1966	28	111	3,198	248	779	552	19	633	15	429
1971	160	5/	768	310	1,254	3,097	29	419	43	296
1976	5/	5/	16	5/	1,299	4,799	172	1,801	5/	5/
1982	5/	80	147	38	849 2/	4,331	923	213	12 3/	NA

See footnotes at end of table.

Continued--

Table 13--Pesticide active ingredient types used on major crops, by region and year--Continued

Item	Northeast	Lake	Corn Belt	Northern Plains	Appa-lachia	South-east	Delta	Southern Plains	Mountain	Pacific
					1,000 pounds					
Other pesticides:										
1964	58	5/	79	5/	14,637	4,042	2,143	6,198	18	2,870
1966	104	163	235	113	10,852	10,545	1,596	2,200	471	9,447
1971	49	5/	433	386	7,277	3,855	3,328	7,376	376	6,699
1976	20	50	321	5/	13,948	6,892	7,987	2,635	920	2,526
1982	5/	5/	72	130	11,540 2/	2,533	4,863	2,922	2,247 3/	NA
Total pesticide quantity:										
1964 4/	5,676	8,789	30,694	11,899	46,893	80,854	33,894	39,067	11,633	16,612
1966	4,466	12,779	56,797	19,165	25,821	46,529	28,888	24,195	12,396	20,126
1971	6,624	31,848	93,242	35,483	29,555	53,680	59,553	39,883	10,742	16,583
1976	15,486	49,290	171,352	54,232	56,597	59,867	75,790	31,784	13,930	19,234
1982	16,642 3/	66,658	215,420	61,059	52,364 2/	43,208	58,521	27,838	15,992 3/	NA

NA = No pesticide data for Pacific region in 1982.

1/ Excludes Connecticut, Delaware, Maine, Massachusetts, New Jersey, New Hampshire, Rhode Island, and Vermont.

2/ Excludes West Virginia.

3/ Excludes Colorado, Nevada, New Mexico, Utah, and Wyoming; includes Washington.

4/ Includes use on tobacco seedbeds and sulfur on any crop.

5/ Less than 10,000 pounds of active ingredient used.

Appalachia and the Delta increased by about eightfold during 1964-82. The Delta ranked sixth in 1964 and rose to fourth by 1971 largely because of increased cotton and soybean herbicide use. Appalachia ranked eighth in 1964 and rose to fifth in 1976 largely because of increased corn and soybean herbicide use. In the remaining regions, herbicide quantity increased steadily from 1964 to 1982 but less rapidly than in these specific regions.

Appalachia, the Delta, and the Southeast typically used the greatest quantity of fungicides on major crops during the surveyed years. These regions generally have greater disease problems than other regions because of climates that are conducive to pathogen growth. Peanuts usually received the greatest quantity of fungicides. However, severe disease problems can erupt in other regions. For example, Corn Belt farmers applied unusually large quantities of fungicides on major crops in 1966 and 1971 and used more than in any other region in 1966.

Appalachian farmers used the largest quantity of pesticides other than fungicides, herbicides, and insecticides on major crops in all years surveyed, but farmers in the Southeast, Delta, and Southern Plains are also historically large users of such pesticides. These pesticides are primarily fumigants (generally for preplant control of tobacco diseases), dessicants and defoliants (harvesting aids for cotton), plant growth regulators (sucker control for tobacco), and miticides (on cotton).

The Corn Belt was the fifth largest user of all pesticides on major crops in 1964, but became the largest beginning in 1966. Pesticide quantity in the Corn Belt increased sevenfold from 1964 to 1982, largely as a result of the rapid rise of corn and soybean herbicide quantities. Appalachia, the Delta, Southeast, and Southern Plains ranked high in 1964 and 1966, but total pesticide quantity fell during 1964-82. Pesticide use fell in those regions because insecticide and fungicide use decreased. The declines are somewhat overstated because the 1964 regional estimates include sulfur use (31 million pounds a.i. in the 48 contiguous States) and fungicide use on tobacco seedbeds, but the estimates for other years do not. The Lake States and Northern Plains moved higher in the national rankings from 1964 to 1982 because corn and soybean herbicide quantity grew rapidly, while the quantity of cotton insecticides fell in other regions.

Conservation Tillage Practices and Pesticide Use

Soil preparation for row crops traditionally has included the use of the moldboard plow to provide a suitable seedbed, incorporate residues into the soil, and control weeds. However, this tillage method also makes most soils more susceptible to wind and water erosion. Conservation tillage practices, introduced in conjunction with the widespread development and application of herbicides for weed control, offer alternative techniques that allow crop residues to remain on the soil surface to decrease the potential for erosion.

Conservation tillage practices include no-till and reduced-till strategies that require varying degrees of field and seedbed preparation. The no-till method requires plant residue to be left virtually undisturbed on the field surface. The soil is broken only when the seeds are planted. The reduced-till method involves varying degrees of soil disturbance, but not turning of the soil.

These alternative tillage practices leave more plant residue on the field, which reduces soil movement, increases soil moisture levels, and lowers soil temperatures. The conventional wisdom holds that pesticide use rises as the intensity of tillage decreases for a number of reasons:

- o Additional herbicide applications are substituted for tillage operations and mechanical cultivation;
- o Increased herbicide applications are needed to ensure effectiveness because additional plant residue ties up a portion of the materials applied; and
- o Increased soil moisture under conservation tillage provides a more accommodating environment for weed and insect pests (13).

Some data documenting pesticide use by type of tillage practice in corn and soybean production do not substantiate the conventional wisdom (18, 43). Per acre herbicide applications in corn production were not significantly different for conventional-till, reduced-till, and no-till strategies in 1980 (table 14). There were differences in average herbicide costs between strategies, however, with no-till farmers spending significantly more because they needed broad-spectrum materials to control a greater variety of weeds. No-till corn farmers also used significantly more insecticide than reduced- and conventional-till farmers, but the difference in insecticide cost was not statistically significant. No-till farmers apparently applied a greater amount of less expensive materials.

The proportion of corn and soybean acres treated with herbicides and insecticides was virtually the same under each tillage practice between 1980 and 1982 (tables 15 and 16, 34). Also, neither per acre corn nor soybean pesticide application rates varied significantly among conventional-, reduced-, and no-till strategies.

Table 14--Per acre corn pesticide use and cost, by different tillage practices, 1980 1/

Tillage practice	Herbicides		Insecticides		All pesticides	
	Use	Cost	Use	Cost	Use	Cost
	Pounds a.i.	Dollars	Pounds a.i.	Dollars	Pounds a.i.	Dollars
No-till	3.50A	17.24A	0.90A	4.60A	4.40A	21.85A
Reduced-till	3.38A	12.70B	.46B	3.16A	3.84A,B	15.86B
Conventional-till	3.00A	11.39B	.45B	3.16B	3.45B	14.55B

1/ Means in each column followed by different letters are significantly different from each other at the 5-percent level. Means are for all farmers, although only 42 percent used insecticides at rates ranging from 1.1 to 1.7 pounds of active ingredient per treated acre. Use of rates per treated acre did not alter the result.

Source: (18).

Table 15--Proportion of planted corn and soybean acreage treated with major herbicides by different tillage practices

Crop/ herbicide	No-till		Reduced-till		Conventional-till	
	1980	1982	1980	1982	1980	1982
			Percent			
Corn:						
Alachlor	43	27	34	40	40	39
Atrazine	73	77	55	66	58	65
Butylate+	7	3	31	35	18	15
Cyanazine	9	29	22	22	18	20
Dicamba	---	7	15	18	10	12
EPTC+	---	*	1	3	3	4
Metolachlor	27	28	9	12	9	16
Paraquat	40	33	*	1	---	1
Pendimethalin	---	2	*	*	1	*
Propachlor	---	---	2	2	3	2
Simazine	---	12	1	1	1	1
2,4-D	12	12	22	23	22	15
Soybeans:						
Alachlor	28	38	29	22	27	29
Acifluorfen	2	12	1	6	2	8
Bentazon	28	15	21	16	23	18
Bifenox	3	---	2	1	1	---
Chloramben	---	4	7	10	6	7
Dinoseb	6	3	2	3	6	8
Fluchloralin	---	---	2	3	4	6
Glyphosate	20	9	7	2	4	*
Linuron	23	24	8	8	11	14
Metolachlor	11	13	3	9	3	9
Metribuzin	26	55	34	39	28	29
Naptalam	6	3	2	3	5	5
Oryzalin	10	3	1	2	1	3
Profluralin	---	---	2	1	2	1
Paraquat	33	26	1	3	1	1
Pendimethalin	2	15	2	2	3	3
2,4-DB	7	7	2	3	3	4
Trifluralin	34	32	53	61	47	48

--- = None reported.
* = Less than 1 percent.

Source: (18).

Farmers practicing no-till make fewer trips across the field and attempt to apply seed, fertilizer, and pesticides in one operation. The use of materials that can be tank-mixed and applied with fertilizers has probably increased. Cyanazine and

Table 16--Proportion of planted corn and soybean acreage treated with major insecticides, by tillage different practices

Crop/ insecticide	No-till		Reduced-till		Conventional-till	
	1980	1982	1980	1982	1980	1982
			Percent			
Corn:						
Carbaryl	4	2	*	*	1	*
Carbofuran	15	18	7	8	12	7
Chlorpyrifos	17	10	5	6	3	3
Ethoprop	---	3	*	1	1	1
Fonofos	4	2	9	9	9	8
Methyl parathion	4	---	---	*	---	*
Parathion	12	---	---	1	---	*
Phorate	---	3	6	10	5	3
Terbufos	4	10	15	15	11	8
Toxaphene	4	5	*	*	*	*
Soybeans:						
Carbaryl	2	2	1	5	3	2
Chlorpyrifos	2	---	---	2	---	1
EPN	2	---	---	---	*	*
Methyl parathion	---	*	1	6	3	5
Methomyl	10	2	2	1	5	3
Permethrin	---	*	---	3	1	4
Toxaphene	2	*	1	3	2	3

--- = None reported.
* = Less than 1 percent.

Source: (18).

simazine, both broad-spectrum, pre-emergence herbicides, were used on more corn and soybean acreage in 1982 than in 1980. Materials that require incorporation into the soil would be used less in a no-till operation. No-till operators used little, if any, butylate or EPTC, both of which are generally incorporated into the soil by tillage.

Insecticide use patterns in row crops vary more than herbicide use because insect infestation varies more than weed emergence. Products recommended for use in no-till operations, such as chlorpyrifos and carbofuran, were applied to a greater percentage of corn no-till acres than to reduced- or conventional-till corn acreage. Insecticides are used less on soybean acreage than on corn acreage, generally in the Southeast where insect infestations tend to be more severe than in other areas. Most soybean insecticides are applied when infestations reach economic loss levels, but most corn insecticides are applied at planting to prevent damage from soil insect infestations. Use patterns among conventional-, reduced-, and no-till practices were similar.

A regional perspective of soybean production methods and input use is available from 1982 (table 17). Average no-till herbicide use and costs per acre in the Midwest were significantly higher than for other tillage practices.5/ Midsouth herbicide use showed no significant difference among tillage practices, although the cost of herbicides used by no-till producers was significantly higher than conventional-till operators.6/ No-till soybean farmers in the Midsouth apparently applied more expensive, broad-spectrum materials. Herbicide use and costs did not differ significantly among tillage practices in the Southeast.7/ Insecticide use and costs were not significantly different among soybean production regions or among tillage practices in 1980.

Corn input use data from 1987 showed statistically significant increases in the percentage of acres treated with herbicides as tillage decreased (table 18). However, 1987 data showed statistically significant decreases in the percentage of corn acres treated with insecticides as tillage decreases. The reason is that farmers rotated more of the moderate-till and no-till corn acreage than the moldboard-plowed corn acreage. Rotating corn often reduces soil insect infestations and the need for insecticides. Thus, 75 percent of the acreage on which corn was continually produced (in 10 major producing States) was treated with insecticides, but only 29 percent of acreage on which corn was rotated with other crops was treated.

Summary of Use Trends

Pesticide use, both in terms of percentage of acreage treated and total quantity, grew rapidly from the 1950's through the 1970's, before stabilizing in the 1980's. Insecticide use was already well established on a high proportion of the acres of many high-value crops susceptible to insect damage, including cotton, tobacco, peanuts, potatoes, and fruits and vegetables, in the 1950's. During the 1960's, the proportion of major field crop acreage treated with insecticides grew rapidly as increased use on corn and soybeans spurred overall growth of insecticide use. The quantity of insecticides used appears to have peaked in the mid-1970's and has fallen since. The decline in insecticide quantity can be attributed to technological advances in the chemical industry heralded by the introduction of insecticides, such as pyrethroids, that are applied at much lower rates than the materials they replaced, the organochlorines and organophosphates.

The acreage of major field crops treated with herbicides also began to increase in the late 1950's. That growth continued until about 1980, when over 90 percent of the acreage of major crops was treated with herbicides. The quantity of herbicides used also increased until the early 1980's.

5/ The Midwest includes Illinois, Indiana, Iowa, Kansas, Kentucky excluding portions along the Mississippi River, Minnesota, Missouri excluding the bootheel, and Ohio.

6/ The Midsouth includes Alabama, Arkansas, portions of Kentucky along the Mississippi River, Louisiana, Mississippi, the Missouri bootheel, and Tennessee.

7/ The Southeast includes Georgia, North Carolina, and South Carolina.

Table 17--Per acre soybean pesticide use and cost, by different tillage practices, 1980 1/

Region/tillage practice	Herbicide		Insecticide		All pesticides	
	Use	Cost	Use	Cost	Use	Cost
	Pounds a.i.	Dollars	Pounds a.i.	Dollars	Pounds a.i.	Dollars
Midwest: 2/						
No-till	3.23A	30.60A	0 A	0 A	3.23A	30.60A
Reduced-till	1.86B	17.65B	.02A	.17A	1.88B	17.82B
Conventional-till	2.03B	17.92B	.02A	.08A	2.05B	17.99B
Midsouth: 3/						
No-till	2.00A	23.68A	.05A	.33A	2.05A	24.01A
Reduced-till	1.74A	18.33A,B	.20A	.73A	1.94A	19.06A,B
Conventional-till	1.45A	15.62B	.17A	1.03A	1.64A	16.97B
Southeast: 4/						
No-till	1.68A	18.87A	.87A	5.92A	2.55A	24.78A
Reduced-till	1.46A	12.01A	.35A	1.88A	1.81A	13.90A
Conventional-till	1.38A	10.87A	.68A	4.71A	2.28A	18.78A

1/ Means in each column followed by different letters are significantly different from each other at the 5-percent level. Means are for all farmers, although only 11 percent used insecticides at rates ranging from 0.8 to 1.6 pounds of active ingredient per treated acre. Use of rates per treated acre did not alter the result.

2/ Includes Illinois, Indiana, Iowa, Kansas, Kentucky excluding portions along the Mississippi River, Minnesota, Missouri excluding the bootheel, and Ohio.

3/ Includes Alabama, Arkansas, portions of Kentucky along the Mississippi River, Louisiana, Mississippi, the Missouri bootheel, and Tennessee.

4/ Includes Georgia, North Carolina, South Carolina.

Source: (18).

Because pesticide use seems to have reached a limit in terms of percentage of acreage treated, the quantity of pesticides used will be influenced primarily by the number of acres planted, the number of treatments per acre, and the application rates per treatment. Pesticide use since 1980 appears to be heavily influenced by acreage planted. Low crop prices and acreage diversion and retirement programs may have reduced pesticide quantities, represented by EPA estimates, below peak levels achieved in the early 1980's.

Pesticide use has grown faster in the Corn Belt and Lake States than in other regions. The major reasons are the rapid increase in corn and soybean pesticide use and the decrease in cotton insecticide quantity in other regions. Because

Table 18--Corn pesticide use and cropping pattern by different tillage practices, 1987 1/

Tillage practice	Herbicides	Insecticides	Continuous corn
	Percent of harvested acres		
Moldboard plow	93	44	32
Moderate-till 2/	96 3/	41 3/	28 3/
No-till	99 3/	40 3/	16 4/

1/ Average for 10 major producing States.
2/ Includes chisel plows, disks, and field cultivators.
3/ Statistically different from moldboard plow tillage.
4/ Not statistically different from moldboard plow tillage because of small number of observations.

Source: (14).

Appalachia, the Delta, and the Southeast periodically have severe pest infestations and grow crops susceptible to pest damage, farmers in those regions are intensive users of insecticides.

Finally, conservation tillage is an important technological trend that could influence pesticide use patterns. The cost advantages of conservation tillage result from less field preparation and mechanical cultivation. Continued substitution of herbicides for mechanical weed control methods is likely to increase chemical pesticide use. Conservation tillage practitioners apply more pesticide and seed to achieve optimal growing conditions. However, some research indicates that type of tillage practice is not always a good indicator of the amount of pesticides used in corn and soybean production.

Pesticide Productivity and Demand

The decision to control pests and the choice of methods are economic. According to economic efficiency criteria, producers should choose the combination of pest control methods that maximizes the difference between pest damage reductions and control costs. They should increase the use of a pest control input until the marginal return (value of damage reduction) of the last input equals its marginal cost. As a result, pesticide use should be influenced by crop prices, alternative control methods, and other production inputs. A farmer makes pest control decisions, however, without knowing the actual pest losses without control, the reduction in pest damage by using a control, and the value of those reductions. Because of that uncertainty, producers must develop expectations of crop value and potential yield savings from control. Rational decisions will retrospectively appear suboptimal if pest infestations or crop values were not as great as anticipated. Because reducing the possibility of large financial losses is important to many producers, some will apply pesticides or other inputs in excess of profit-maximizing levels.

Pesticide Productivity

Several studies have shown pesticides to be efficient productive inputs. Headley used 1963 data to estimate that $1 spent on pesticides had a $4 return (39). Campbell estimated a return of $5 to $13 per insecticide dollar in apple production (6). These studies state that the marginal return in using a chemical pesticide is much greater than the marginal cost, implying that economic efficiency would dictate greater amounts of pesticide use. However, these and other studies have been criticized for not including a measure of pest infestation which influences the productivity of pesticides in some cases. Lichtenberg and Zilberman also claim that the Cobb-Douglas specification used in those studies overestimates pesticide productivity and underestimates the productivity of other inputs by not including a kill-efficiency function for the pesticide input (47). So, the high marginal returns reported by Headley and Campbell may result from misspecification of the equation. Using 10 years of experimental data, Hawkins, Slife, and Swanson estimated an average return of $3.30 to $4.90 per herbicide dollar in corn production compared with not using herbicides but increasing cultivation (37).

Other studies show lower returns. Carlson showed that the productivity of cotton insecticides declined from the period 1964-66 to 1966-69 (8). He attributed much of this decline to increased insect resistance to organochlorines and showed a shift in demand to organophosphates. Lee and Langham used 1964-68 data to estimate that the marginal returns to pesticides used in citrus production were less than marginal cost, which implies overuse of pesticides (45). Their study simultaneously estimated production and insect population levels and included a kill-efficiency relationship.

Miranowski used a quadratic specification for pesticide use and 1966 data to show returns of $2.02 for insecticides and $1.23 for herbicides per dollar spent in corn production (51). During that same year, the returns for cotton were $0.09 for insecticides and $1.82 for herbicides. Cotton insecticide use did not justify costs that year. Whether farmers' expectations justified that use is not clear. Duffy and Hanthorn showed average returns for corn insecticides used in 1980 to be $1.03 per dollar spent and $1.05 for herbicides (18). Their estimates for 1980 soybeans were $0.57 per dollar spent for insecticides and $1.13 for herbicides. Their study used a linear specification for pesticide use (and a dummy variable indicating whether or not soil insecticides were applied to corn) and included pest infestations. To some degree, these low returns may have been the result of low pest infestations and crop yields, because 1980 was a dry year. However, a decline in marginal productivity as pesticide use increases is expected.

Pesticide Prices and Demand

Pesticide, crop, and other input prices theoretically affect pesticide use. Declines in pesticide prices in relation to crop and other input prices would increase the relative marginal return of pesticides and encourage farmers to substitute pesticides for other inputs. The result would be increased pesticide use. An increase in pesticide prices in relation to crop prices or other input prices would discourage pesticide use. Daberkow and Reichelderfer cited several studies showing that declines in agricultural chemical (pesticide and fertilizer) prices in relation to crop and other input prices encouraged growth in agricultural chemical use (15).

Growth in pesticide use is often attributed to cost-effectiveness in relation to other pest control methods. Pesticides have been increasingly substituted for labor since the 1950's (figs. 1 and 2). Also, herbicide use has helped to reduce tillage, reducing time, labor, fuel, and machinery use in weed control. Pesticides fit well into mechanized agriculture. Many products can be applied during other operations such as planting or tillage, saving farmers time at critical points of the growing season and giving them the ability to manage larger operations.

Technical advances may have encouraged use of pesticides in relation to other inputs to take advantage of relatively lower costs. Capalbo and Vo cite several studies that indicate labor-saving technical change in agriculture since the end of World War II (7). Shoemaker found technical change increased use of all inputs except labor in relation to land (66).

The trends in relative price ratios and pesticide use are consistent with the argument that relative prices influence pesticide use. Prices and use show different trends during two time periods: 1950-71 and 1972 to the present.

The pesticide price index generally fell during 1950-71 (fig. 16).8/ Pesticide prices fell in relation to both crop prices and wages, but the fall was much more dramatic in relation to wages (fig. 17). Crop prices and production were heavily influenced by acreage control programs, and petroleum prices were low. Since 1965, when USDA initiated price indexes for farm machinery and fuel, pesticide prices have also fallen in relation to prices of those two inputs (fig. 18). Falling relative pesticide prices encouraged substitution of pesticides for labor, fuel, and machinery, and pesticide use grew rapidly during this period.

After 1971, important changes in pesticide price and use trends occurred. From the mid- to late 1970's through at least the mid-1980's, pesticide prices deviated from the general downtrend in relation to crop and other input prices and that may be the result of higher petroleum prices, greater pesticide demand, or both. Whether that deviation is simply a pause in a long-term downtrend or the beginning of an uptrend or relative stability is unclear.

Pesticide prices rose rapidly from 1971 until 1984 and declined thereafter (fig. 16). Petroleum shortages contributed to rapid price increases around 1974 and during 1979-81. During 1974-80, pesticide prices rose faster than crop prices, but not as fast as wages and fuel prices. The ratio of pesticide prices to crop prices fell rapidly during 1968-74 as crop prices climbed, but that ratio has generally risen since then (fig. 17). Indexes show that pesticide prices continued to fall in relation to wages, farm machinery, and fuel until 1979 or 1980 (figs. 17 and 18). Total pesticide use and the percentage of planted acreage treated for such major field crops as corn, soybeans, and cotton increased rapidly from 70-80 percent in 1971 to over 90 percent in 1980 (figs. 5, 6, 7, and 12 and tables 4 and 9). After 1980, falling crop prices contributed to a rising pesticide/crop price ratio. Pesticide prices increased in relation to wages until 1983 and then fell. Pesticide prices rose in relation to fuel prices and remained stable in relation to farm machinery prices.

The period of stable or rising relative pesticide prices may have acted as a brake on the growth of pesticide use, because that period preceded the slowing of

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8/ The pesticide price index was developed by V. Eldon Ball, Resources and Technology Division, Economic Research Service.

Figure 16
Pesticide price index

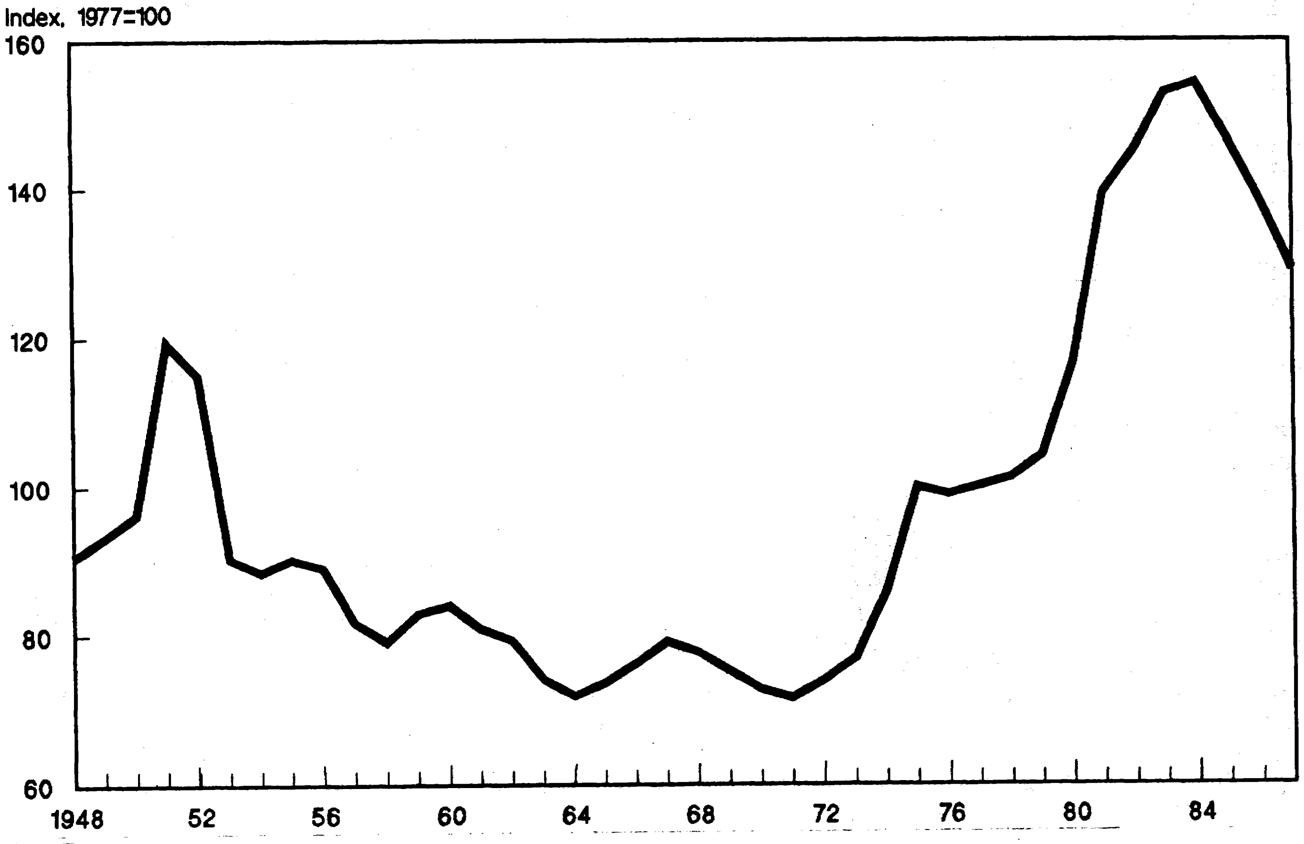


Figure 17
Relative cost of pesticides compared with crop prices and labor costs

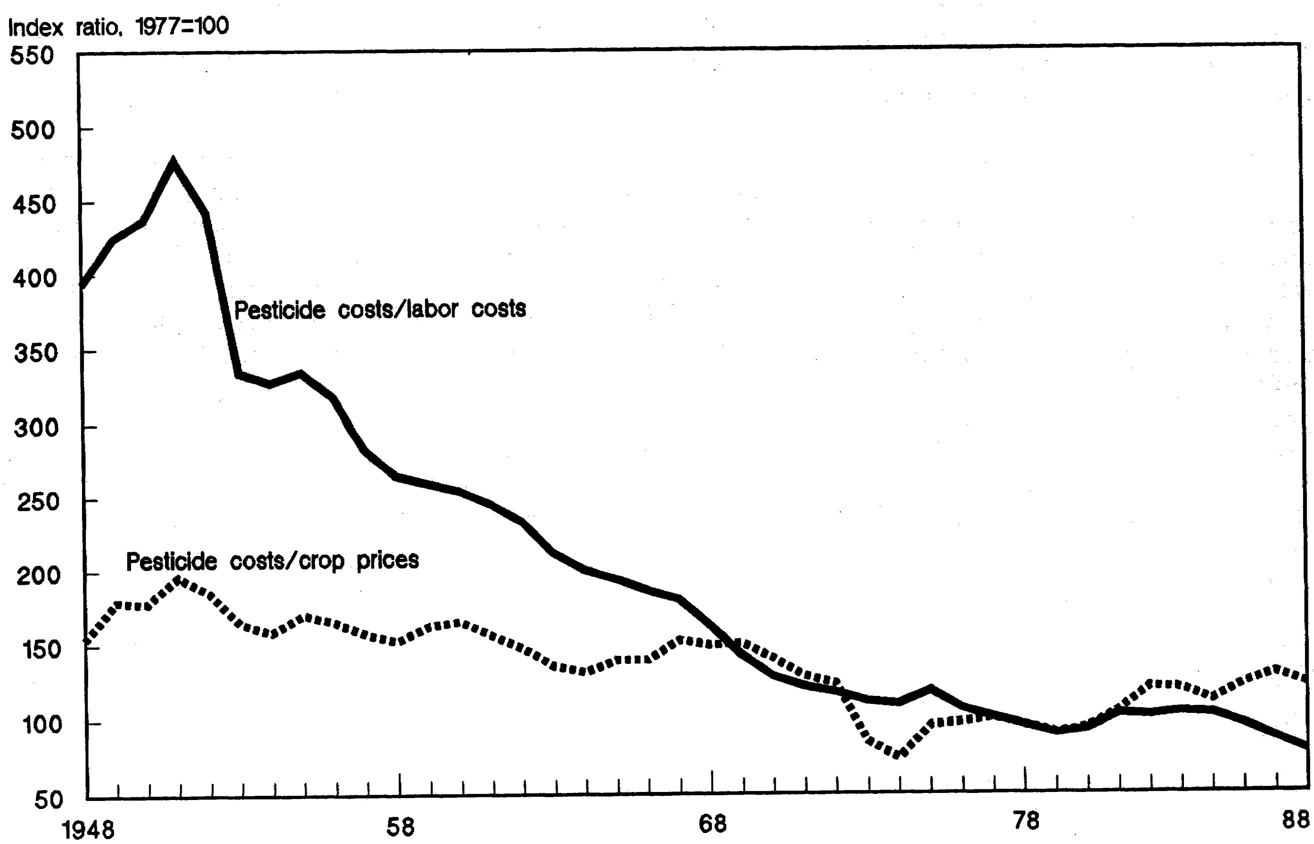
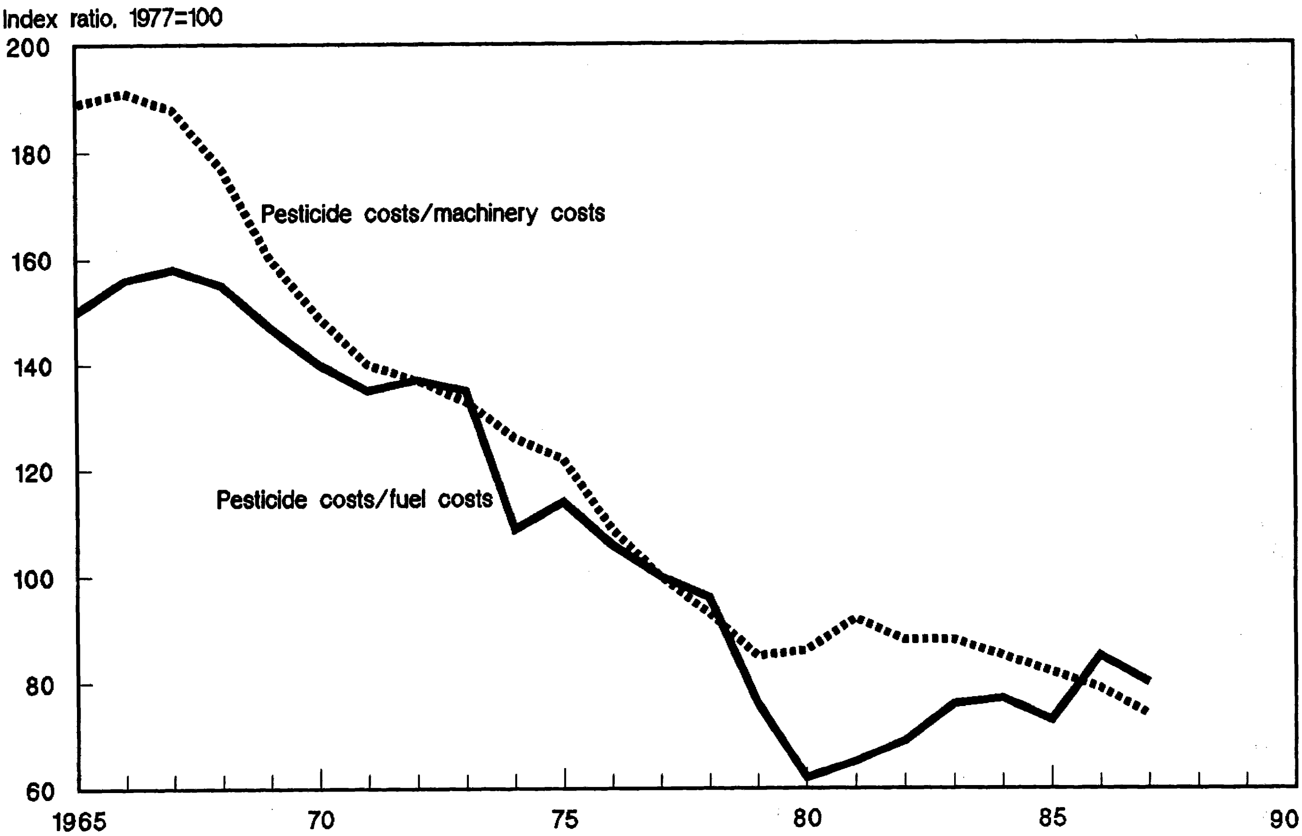


Figure 18
Relative cost of pesticides compared with machinery and fuel costs



pesticide use growth from 1979 to 1982 and the decline that followed (fig. 5). However, separating the roles that stable or rising relative pesticide prices and other factors played in slowing pesticide use growth is difficult. Such a large percentage of crop acreage was treated with pesticides by 1980 that growth would probably have slowed even if pesticide prices had continued to decline (tables 4 and 9). The idling of large acreages under Government programs after 1981 appears to have been a major factor in slowing the growth in pesticide use. The decline in the pesticide price index after 1984 is associated with a decline in pesticide use and may be a response to reduced demand caused by lower crop acreage and prices.

The response of pesticide purchases to price changes can be measured by price elasticity. The more the quantity purchased decreases (increases) in response to an increase (decrease) in its own price, the more price elastic is the demand. Capalbo and Vo cited several studies that showed demand for agricultural chemicals (pesticides and fertilizers) to be price inelastic, meaning that the percentage change in quantity purchased was less than the percentage change in price (7). Those results indicate that pesticide use changed relatively little in response to price changes.

Studies addressing pesticide demand relationships are rare. One would expect that the price elasticity of an individual pesticide would increase as the number and effectiveness of alternatives increase. If alternatives are unavailable or much less cost-effective, producers are less likely to change pest control practices when prices change than otherwise. When several alternatives are available to control a particular pest, one would expect the demand for all pesticides used to control that pest to be less elastic than the demand for one of the alternatives.

Miranowski estimated pesticide demand with a variety of methods, using cross-section data to examine insecticides and herbicides on corn and cotton and time-series data for all domestic uses of 2,4-D, DDT, and cyclodiene insecticides (51). He found that the demand for major groupings (insecticides and herbicides) tended to be inelastic with respect to product price and chemical price. Miranowski concluded that individual pest control chemicals were not responsive to changes in output prices but were very responsive to changes in chemical prices. The rationale was that crop price influences the decision to treat, but the choice of chemical is influenced mostly by the costs of alternative control methods.

Carlson used time-series data to examine demand for organophosphate and organochlorine insecticides (8). He found demand for those insecticides to be generally elastic, indicating the availability of alternatives in the long run. (However, the demand for DDT in one specification was inelastic.) Pesticide resistance was highly significant in explaining reduced use of organochlorines and increased use of organophosphates.

Effects of Farm Programs

An important issue is how Government farm programs affect pesticide use. Around 1970, several researchers argued that the combination of price supports and acreage diversion encouraged farmers to substitute pesticides and fertilizers for land (9, 22, 41, 61, 64). The result would be faster growth for pesticide use or more intensive pesticide use, or both, than under free market conditions. Richardson reasoned that the programs hastened agriculture's adjustment toward the optimal mix of pesticides and other productive inputs (minimum production cost per unit of output) but, during 1965-69, had not encouraged overuse of pesticides (64).

Miranowski (51) discussed four ways that programs could affect pesticide use:

- Price effect. Higher prices (caused by acreage controls or inventory programs) or price guarantees (through target prices and loan rates) increase per acre pesticide use.

- Acreage effect. Reduced acreage limits pesticide use by restricting the crop acreage that could be treated, offsetting the price effect, at least partially.

- Location effect. Production of some crops, such as cotton and soybeans, shifts from lower pesticide use areas to higher ones where production would be less economically feasible without the price and income support programs.

- Crop-mix effect. More acreage is planted to crops with relatively high pesticide use per acre.

These arguments are well founded in economic theory because pesticides should be applied until their marginal return equals marginal cost. Farm programs can create higher marginal crop and pesticide use returns than free markets under two circumstances:

- o If target prices or loan rates exceed market prices and program payment yields are a function of past production (affecting only program participants); or

- o If acreage diversions or crop storage programs encourage higher market prices than free markets would (affecting both participants and nonparticipants).

These higher marginal returns could encourage higher application rates per acre, more treatments per acre, or a greater percentage of acres treated, as well as the location and crop-mix effects described by Miranowski. Maintaining marginal returns at higher levels than market prices would dictate lower pesticide treatment thresholds for allowable pest populations in program crops. Acreage controls limit the acreage that can be treated, but such controls may encourage farmers to increase program yields to increase payments. Base acreage requirements could discourage crop rotation, thereby encouraging higher populations of some pests and more pesticide use. Hence, the programs could encourage more intensive pesticide use and more substitution of pesticides and fertilizers for land than would free markets.

The administrative freeze of farm program yields under the Food Security Act of 1985 should sever any relationship between target prices (deficiency payments) and pesticide use. However, if loan rates exceed free market price expectations, the loan rates could also encourage greater pesticide use than would free markets. Also, if acreage diversion and retirement programs encourage higher market prices than would free markets, these programs would continue to encourage greater pesticide use than would free markets.

Program effects provide a plausible explanation for the growth path of pesticide use as demonstrated by the percentage of acreage treated and pesticide quantity used, particularly on program crops. The growth rate was high in the 1960's and early 1970's, when support levels exceeded market prices and acreage was diverted. Price supports and acreage controls could have encouraged higher pesticide use per acre and a more rapid increase in use than free markets would have. Programs also could have encouraged more production of cotton and other program crops in the Southeast, an area with relatively severe pest problems, than free markets would have. (Moreover, termination of acreage allotments by 1977 may have facilitated a shift of cotton acreage to the Southwest and West, where pesticide use is less.) The high growth rate continued for herbicide use throughout the remainder of the 1970's, when market prices exceeded target prices, crop exports were growing, and acreage was not diverted. High market prices could have encouraged continued high per acre use rates and growth in the percentage of acres treated. Growth in planted acreage contributed to increases in total quantity used.

After 1980, acreage planted and the severity of pest problems seem to be major factors affecting the variation in pesticide use, because growth in the percentage of acres treated appears to have reached a limit for most major crops. After 1982, target prices exceeded market prices in some years and could have encouraged more pesticide use per acre and a greater percentage of acreage treated. However, acreage diversion often contributed to decreases in total quantity of pesticides used. Quite noticeable was a decrease in EPA's pesticide use estimate during the 1983 Payment-in-Kind Program (fig. 5). The administrative freeze of program yields and long-term acreage retirement under the CRP after the Food Security Act of 1985 may contribute to lower use per acre.

(Herbicides might be used on CRP acreage, but the amount would probably be less than if the land were used to produce such crops as corn, soybeans, or cotton.) EPA's estimate of pesticide quantity used decreased noticeably in 1986 and 1987. However, additional survey data collected since 1985 have been too limited to show trends in pesticide quantity (pounds of active ingredient) on individual crops.

The level and growth rate of pesticide use could be due entirely to the cost effectiveness of pesticides in relation to other pest control inputs. Neither the reduction in growth rate for the percentage of acreage treated nor EPA's quantity estimate noticeably dropped when market prices began to exceed target prices in the 1970's. We have conducted no statistical tests, but the scarce time-series data do not appear to invalidate either argument about the effect of farm programs on pesticide use. However, if pesticide use per acre or the percentage of acreage treated has not fallen since the freeze of program yields despite low market prices for program crops, target prices apparently have little effect on pesticide use.

Cross-sectional analysis would be another way to examine the question. One could compare pesticide use on farms participating in Government programs to similar farms not participating in the programs. The hypothesis that programs encourage greater pesticide use would be supported if more pesticides were used on participants' farms. USDA pesticide use surveys, however, have never identified program participation. But, pesticide expenditures on participating and nonparticipating farms could be obtained from USDA Farm Costs and Returns Surveys and compared.

Pest Control Issues

The overwhelming adoption of chemical pesticides in post-World War II agriculture has contributed to significant productivity gains by protecting yields and replacing less efficient production inputs. However, during the 1960's, some biologists claimed that overuse of pesticides could increase pest damage and pest control costs and, thus, be counterproductive.

Some Pesticide Applications Can Be Counterproductive

Scheduled or prophylactic treatments to control low pest infestations may have little effect on yield, and the value of damage reduction might not exceed cost. Some applications destroy beneficial organisms and natural enemies to pests. For example, early season application of some cotton insecticides can reduce natural enemies to bollworm and tobacco budworm. The resulting secondary outbreaks could require additional treatments. The destruction of natural enemies could also create pests from species not previously considered damaging because population levels were low. Adkisson termed bollworm and tobacco budworm, currently the most damaging of cotton insect pests, secondary pests unleashed from natural control by treatments to control fleahoppers and boll weevils (1). Adkisson also discussed the drift of methyl parathion from cotton fields to nearby citrus orchards, killing natural enemies of brown soft scale and thus requiring pesticides to control that pest. The use of pesticides in concert with genetically uniform high-yielding varieties without regard for pest susceptibility and practices such as irrigation, fertilization, and monoculture often create situations that repress natural controls to pest outbreaks.

Continued exposure of pest populations to a chemical leaves the most resistant individuals. Increases of resistant populations reduce the effectiveness of the chemical. A natural response is to use more of the pesticide, which simply aggravates the problem. The development of resistance coupled with diminished natural predators sets up a situation for damaging pest population growth.

The problem of pest resistance is well demonstrated by the example of cotton insects. DeMichele and Bottrell reported 24 species of insect and spider mite pests of cotton that had developed resistance to one or more cotton insecticides by 1976 (17). In many cases, these insects developed resistance to the organochlorine and carbamate compounds (1). Some insects developed resistance to the organophosphate products in regions where those products were used extensively to combat the organochlorine-resistant pests. Carlson stated that resistance of cotton insects to organochlorines encouraged the decline in organochlorine use and rise of organophosphate use discussed above (fig. 10, 8). Because the organophosphates have less residual effectiveness, more frequent applications resulted in higher user costs and toxicity to humans and other nontarget organisms. These problems partly motivated the search for other methods of pest control in cotton including the development of insect-resistant varieties, natural enemies, microbial pesticides, pheromone traps, and other methods that could be used in a multifaceted, integrated approach to the control problem. Since 1977, synthetic pyrethroids have largely replaced organophosphates for bollworm and tobacco budworm control, but evidence is accumulating that cotton insects are developing resistance to the pyrethroids as well (78).

The counterproductive effects have motivated biological and economic studies in two areas: economic thresholds and integrated pest management. Closely related are large-area programs to control mobile pests. These concepts have been included in the pest control strategies for a number of high-value crops including cotton, fruits, and vegetables.

Economic Threshold

The economic threshold is a response to the alleged overuse of pesticides and defines an alternative to scheduled or prophylactic treatments. The theory of the economic threshold is based on the notion that pests should be controlled only when the value of damage reduction exceeds the cost of control (69). The threshold defines whether or not pesticide applications should be made, as well as the optimal level of pest infestation or damage. Headley and Hillebrandt defined an optimal dosage and threshold population where the marginal value of damage reduction equals marginal cost (41, 43). Pesticide dosage and threshold levels vary with crop prices and control costs, according to economic theory. The implementation of economic thresholds requires pest monitoring and damage projection.

The variability of return (risk) and imperfect information (uncertainty) complicate the threshold concept. Risk encourages risk-averse farmers to increase pesticide use to reduce the probabilities of large losses (52, 56, 73). As a result, Turpin suggested that crop insurance might reduce the risk of infrequent, but heavy, damage at less cost than insecticide use (72). Feder said that both risk and uncertainty encourage higher pesticide dosages or lower thresholds resulting in higher pesticide use (23). Improving information about pest damage through monitoring and damage projection, and improving the accuracy of such estimates, can reduce uncertainty. Reduced uncertainty can lower pesticide dosages and increase treatment thresholds that lead to reduced pesticide use.

The economic threshold concept is dynamic because allowable pest populations depend upon the life cycle of the plant, planting and harvest dates, infestation timing, cost of the chemical control, and expected crop price. By eliminating uneconomic pesticide applications, thresholds can reduce pest control costs, destruction of beneficial species and natural enemies to pests, pest-resistance development, and adverse health, safety, and environmental effects. The costs include pest monitoring and additional management skills.

Integrated Pest Management

In the 1960's and 1970's, the counterproductive effects of many pesticide applications forced many biologists to rethink what constitutes optimal pest control methods. The result was integrated pest management (IPM). The notion of "managing" insect pests was proposed by Geier and Clark (28). More recently other crop pests including weeds, nematodes, and plant pathogens have been included in an expanded perception of IPM. One of the most important challenges for IPM is maintaining the effectiveness of pyrethroids now that some evidence shows bollworm and tobacco budworm are becoming resistant to them.

IPM focuses on optimizing the use of biological and cultural controls, including plant resistance to pests and the augmentation of natural enemies of pest species, with chemical controls to manage pest populations rather than relying on a single method (67, 69). IPM includes the use of economic thresholds and pest monitoring. The cultural and biological controls that had in many instances proved adequate in a more primitive agriculture were retooled to apply more generally to modern farming systems. Such methods include, but are not limited to, sanitation (destruction or utilization of crop refuse), tillage to destroy overwintering insects and pathogens, removal of alternative hosts of pathogens and insects, rotation of crops to discourage buildup of damaging populations of insects and pathogens, timing of planting dates to avoid high damage-prone periods, use of insect- and pathogen-free seed and seeding methods, use of trap crops, selection of planting sites, pruning and defoliation, isolation from other crops, and management of water and fertilizer (68).

Several studies show that risk-averse farmers, in an IPM context, may choose technologies that reduce pesticide use. Some technologies (scouting, trap crops, augmentation of natural enemies) may reduce pesticide treatments and variability of returns (32, 46). Crop rotation can reduce pest damage and diversify against nonpest sources of risk such as bad weather or price variability (44).

The success of IPM, however, has been mixed. The residual effectiveness of many chemical insecticides has diminished the importance in some commodities of a key tenet of many IPM programs, the timely application of a chemical pesticide when an economic threshold is reached. Recent research in soybean pest control has shown that premature application errors had little effect on net returns when compared with strict threshold compliance, allowing farmers to maintain a high level of crop protection without incurring the costs involved in IPM program participation (70).

The most successful adoption has come with such crops as cotton, fruits, and vegetables, where the per acre use and cost of insecticides are high. A national evaluation of Extension Service IPM programs estimated a gain of $578 million per year for IPM users over nonusers in 15 States (62). However, due to the extreme variability of the sample data, only 3 of the 15 States showed statistically significant differences in net returns between IPM users and nonusers. Also, average pesticide and pest management costs were often higher for IPM users than nonusers. Thus, any gains to IPM users were due to higher output or prices received. Gianessi and Greene cited several studies where IPM reduced pesticide applications and costs for vegetables and stated that adoption by growers varies considerably by crop (30).

Large-Area Programs

Mobile pests, such as the boll weevil, create special problems. Such pests may reinfest treated fields from untreated areas. Mobile pests can also spread resistance from one location to another. With such a pest, some farmers may underestimate the total damage caused, because some damage occurs elsewhere, and decide not to treat. From the viewpoint of total damage to all farmers, it may be more desirable for them to control the pest.

Group action, private or Government, can improve the effectiveness of managing mobile pests and resistance. There have been a variety of cooperative pest control efforts (31), such as the Fillmore Crop Protection District (32) and recent USDA-supported attempts to eradicate the boll weevil in the Southeast (10). Eradication programs could increase pesticide use to eliminate low infestations that individuals would find uneconomical to control. Successful control could reduce future applications and, perhaps, total pesticide use over time. Eradication of the boll weevil may help to reduce early-season pesticide applications that kill natural enemies to bollworm and tobacco budworm and, thus, reduce treatments for those two pests.

Effects on Pesticide Use

The effects that thresholds, IPM, and large-area programs have had upon pesticide use are not clear. Thresholds and IPM have probably not had much effect on total acreage treated. Cotton insects are an important target for these strategies, and 48-65 percent of total cotton acreage has been treated with insecticides since the 1950's with no apparent trend. However, these strategies may have reduced the number of pesticide applications (such as cotton insecticides) and influenced the mix of pesticide products and the total quantity used on specific crops such as cotton, fruits, and vegetables.

Health, Safety, and Environmental Issues

Until the mid-1960's, the primary purpose of pesticide regulatory policy was to protect consumers from ineffective and acutely toxic products (54, 87). Since the 1960's, the American public has expressed concerns about potential health, safety, and environmental effects of pesticide use. These concerns have led to major changes in the pesticide regulatory process. Important issues have included food safety, farmworker safety, cancer risks, birth defects, wildlife mortality, and, more recently, ground water pollution and protection of endangered species. Not surprisingly, the issue of ground water contamination by agricultural pesticides has alarmed the farm community.

Pesticide Regulatory Policy

Pesticide regulatory policy was initiated with the Insecticide Act of 1910, which prohibited the manufacture, sale, or transport of adulterated or misbranded pesticides and which protected farmers and ranchers from chemical manufacturers' possible improprieties in marketing either ineffective or indiscriminately toxic products. The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1947 required that all toxic chemicals for sale in interstate commerce be registered against manufacturers' claims of effectiveness by the USDA. Pesticide registrations are essentially licenses that define permitted crops, livestock, methods of use, or locations of use for pesticide products. FIFRA further required that the product label specify content and whether the substance was poisonous.

Concerns about food safety emerged in the 1950's. The Delaney Report addressed the problem of chemical residues in foods and recommended that a portion of the Federal Food, Drug, and Cosmetic Act (FDCA) be amended to require proof of a chemical's safety prior to distribution in a food product. The Miller Amendment to the FDCA in 1954 did expressly this by simplifying the procedure under which pesticide residues (tolerance levels) on raw agricultural commodities are regulated. The 1959 Nematocide, Plant Regulator, Defoliant, and Desiccant Amendment to FIFRA also required the establishment of tolerance levels for these materials.

The 1962 publication of Rachel Carson's <u>Silent Spring</u> focused public attention on the potential dangers of chemical use to the environment (<u>11</u>). In 1964, FIFRA amendments included provisions for suspension and cancellation proceedings to prevent imminent hazards. DDT and other organochlorines became an issue because of their persistence in the environment and accumulation in animal fatty tissues. In 1969, the Environmental Defense Fund petitioned USDA to cancel DDT's registration.

Authority for administering FIFRA and the pesticide regulatory functions of FDCA was transferred to EPA when it was created in December 1970 (<u>12</u>). FIFRA was amended in 1972 by the Federal Environmental Pesticide Control Act (FEPCA), which allowed for the first time the banning of pesticides if evidence could be established that use led directly to environmental damage. Congress mandated that EPA begin to assess the approximately 35,000 pesticide products previously registered by Federal and State authorities. The mandate required reregistration of all pesticide products within 4 years using current health and environmental protection criteria. Materials that exceeded those criteria were subject to cancellation of registration, but only after a comparison determined that risks outweighed benefits. The procedure was once called Rebuttable Presumption Against Reregistration (RPAR), but it is now called Special Review. FEPCA also established a process by which applicators of pesticides would be certified, adding a measure of safety to the application process and addressing the acute toxicity problem.

The 1978 FIFRA amendments eliminated the deadline for reregistration but required an expeditious process. Rather than a product-by-product approach, the 1978 amendments allowed EPA to evaluate the 600 active ingredients used in product formulations. The 1978 amendments also gave the States primary enforcement authority for pesticide use, but they authorized EPA to suspend that authority if a State lacked the proper controls. The amendments also allowed States to approve pesticide use to meet special local needs, simplified the procedures for registering a pesticide, and required that applicants for pesticide registration who use test data developed earlier by another manufacturer compensate the original data developer. FIFRA amendments passed in 1988 will speed the reregistration process and provide EPA with additional financial resources. These funds would originate from a system of fees levied on both the basic manufacturers of active ingredients and formulators of pesticide products.

Table 19 summarizes EPA's regulatory actions against some major agricultural pesticide products. Cancellation is the revocation of a pesticide's registration for a particular use. Cancellations require a Special Review including an evaluation of risks and benefits. Suspensions are the emergency withdrawal of a pesticide from the market. However, a Special Review is required before a suspended chemical's registration can be cancelled. Regulatory actions do not have to be so drastic. For example, registrations can be modified to require protective clothing, changes in application methods, or application by a certified applicator. Finally, suspensions and cancellations are not the only way a chemical can be removed from the market. Rather than meet certain requirements, registrants may prefer to lose a registration, voluntarily change a label, or withdraw a product.

Although many of the Special Reviews were initiated in the 1970's, regulatory actions were taken early in the 1980's. The review process, right of appeal, and other proceedings, make EPA's Special Review procedure one that requires, in many instances, years to complete. Between 1981 and 1986, few special reviews were initiated. Reviews of alachlor, daminozide, EDB, and dinoseb were notable exceptions. Regulatory activity is increasing with investigations of fungicides and concerns for endangered species and ground water contamination.

Since the 1972 congressional mandate, only one active ingredient of the 600 that are used in the formulation of approximately 50,000 pesticide products has completed a final reassessment. As of 1986, EPA had completed a preliminary assessment of 130 active ingredients. In a preliminary assessment, EPA evaluates the data it has on file and identifies additional areas where testing may be necessary to complete the reregistration process. From the inception of the RPAR or Special Review program in 1975 through November 1985, EPA completed 32 Special Reviews. As a result, EPA cancelled all uses of 5 active ingredients, cancelled some uses or imposed restrictions on certain uses of 26 other ingredients, and took no action on one ingredient (87).

Under recently passed FIFRA amendments, the reregistration program will accelerate. The number of pesticide products that are suspended, cancelled, or restricted to limited use will probably increase as the reassessment continues. Recent advances in toxicological methods have improved the determination of human and environmental effects of specific product uses. The listing in table 19 may grow significantly during the 1990's.

The dramatic change in the emphasis of pesticide policy toward protection from health, safety, and environmental risks has had little effect on the percentage of acreage treated with pesticides. Acreage has steadily increased since 1972. Continued growth in herbicide use has been especially dramatic. However, cancellations, suspensions, and use restrictions have affected the individual compounds and the mix of pesticides used. Regulatory actions contributed indirectly to the decline in organochlorine insecticide use from about 70 percent of total insecticides applied in 1966 to about 5 percent in 1982 (fig. 9). Thus, regulatory activity may have contributed to the decrease in insecticide quantity

Table 19--EPA regulatory actions on selected pesticides, 1972-88

Active ingredient	Action of chemical	Regulatory action and date 1/
Alachlor	Control of grasses and broadleaf weeds in corn, soybeans, peanuts.	Restricted use, 1987.
Aldrin	Control of soil insects.	Cancelled for all uses except termite control, 1974. Voluntarily cancelled for termite control, 1987.
Benomyl	Systemic fungicide for fruits, nuts, vegetables field crops, turf, and ornamentals.	Cancelled for aerial spraying use, 1982.
BHC	Control of cotton insects.	Cancelled for all uses, 1978.
Captafol	Foliar fungicide for apples, cherries, tomatoes.	Voluntarily cancelled, 1987.
Chloranil	Seed fungicide treatment.	Voluntarily cancelled, 1977.
Chlordane	Control of soil insects.	Cancelled for agricultural uses, 1978. Voluntarily cancelled for termite control, 1988.
Chlordimeform	Control of bollworms and tobacco budworm on cotton.	Voluntarily cancelled, 1988.
Chlorobenzilate	Control of mites in citrus.	Cancelled for all uses except restricted use on citrus, 1979.
DBCP (dibromochloropropane)	Soil fumigant.	Voluntarily cancelled for all uses except on pineapple in Hawaii, 1981. Cancelled for all uses, 1985.

See footnote at end of table.

Continued--

Table 19--EPA regulatory actions on selected pesticides, 1972-88--Continued

Active ingredient	Action of chemical	Regulatory action and date 1/
DDT	Broad-spectrum insecticide.	Cancelled for all uses except control of vector diseases, health quarantine, and body lice, 1972.
Dieldrin	Control of soil insects.	Cancelled for all uses except termite control, 1974. Voluntarily cancelled for termite control, 1987.
Dinoseb	Contact herbicide desiccant.	Cancelled for all uses in 1987, except dry peas, snap beans, cucurbits, cranberries, green peas, lentils, and chick peas in Idaho, Oregon, and Washington for 1988, and cranberries in Washington and Oregon for 1989.
EBDC's (Mancozeb, Maneb, Metiram, Nabam, Zineb)	Fungicide for fruits, vegetables, and field crops.	Label changes including use of protective clothing and hazards to wildlife, 1982.
EDB	Fumigant for soil application and stored products.	Cancelled for all uses except exported citrus and papaya, termites, vault fumigation, and APHIS Japanese beetle control program, 1984.
Endrin	Control of insects in cotton and small grains.	Cancelled for all uses, 1985.
EPN	Control of corn borer, bollworm, boll weevil, tobacco budworm.	Voluntarily cancelled for all uses, 1987.
Heptachlor	Control of soil insects.	Cancelled for all agricultural uses, 1983.

See footnote at end of table.

Continued--

Table 19--EPA regulatory actions on selected pesticides, 1972-88--Continued

Active ingredient	Action of chemical	Regulatory action and date 1/
Lindane	Seed insecticide treatment.	Cancelled for all registered uses except restricted use for commercial ornamentals, avocados, pecans, Christmas trees, structures, and dog shampoos and dusts, 1984.
Silvex	General weed control.	Cancelled for all uses, 1983.
2,4,5-T	Control of woody plants, weed control in rice.	Cancelled for all uses, 1983.
Toxaphene	Control of cotton insects, grasshoppers, armyworms.	Cancelled for registered uses except restricted use for scabies on sheep and beef cattle; mealy bugs and pineapple gamosis moths on pineapple; weevils on bananas in the Virgin Islands and Puerto Rico; and armyworms, cutworms, and grasshoppers under emergency conditions on cotton, corn, and small grains, 1983.

1/ Restricted use pesticides must be applied by or under the direct supervision of a certified applicator.

(pounds of active ingredient) used. EPA has also ordered label changes that have prescribed different methods of application and the use of safety equipment.

Current Issues

Pesticide pollution of ground water has recently become a major issue in the United States. Nielsen and Lee estimated that 1,128 counties had potential pesticide contamination of ground water (55). Approximately 46 million people use ground water that may be contaminated with pesticides. About 18 million people rely on private wells that are more susceptible to contamination than deeper, regulated public wells. Ground water in 1,437 counties, or about 46 percent of counties in the conterminous States, may be contaminated by pesticides or nitrogen fertilizers. About 70 percent of the cropland in those 1,437 counties was planted to corn, soybeans, and wheat. Those crops account for a major portion of pesticide use. The ground water contamination potential is especially acute in regions of the Corn Belt, Lake States, eastern seaboard, and gulf coast. EPA has determined that many of the most effective and heavily used products have significant leaching ability, including the herbicides alachlor, atrazine, cyanazine, and metolachlor. The EPA is proposing plans that emphasize State management of ground water problems, but ground water contamination could cause the modification or cancellation of pesticide registrations.

The Endangered Species Act (ESA) of 1974 provides for protecting the habitat of threatened plants and animals from potentially toxic chemicals. When implementing the ESA in 1988, EPA designated counties containing eligible species to be zones free from pesticides that are toxic to those species. Implementation of such an action would disrupt agricultural production and marketing practices in specific areas. The proposed program caused sufficient furor in the agricultural community for EPA to reconsider its proposal. The proposal will probably be modified following input from a series of regional public hearings, and interaction with the States, Fish and Wildlife Service, environmental interests, farm groups, and USDA. EPA will probably not implement a revised approach until 1990.

Assessing Benefits

Assessing benefits and risks is a major component of the Special Review process. EPA is responsible for those evaluations. However, USDA provides benefits information to EPA and makes independent assessments of benefits to examine the implications of proposed regulations on agriculture.

Evidence of risk is EPA's reason to initiate a review. Thus, regulatory process puts the burden of proof on demonstrating benefits large enough to justify a pesticide's registration. The assessment of benefits is essentially the same as estimating the social efficiency loss, excluding health and safety effects, of removing the pesticide from the market and switching to the best alternative controls, if any. If the alternatives are less effective or more expensive, or both, the cost per unit of output will increase.

The first step, then, is estimating the cost-effectiveness of an active ingredient compared with its alternatives. The assessment requires estimates of the pesticide's use, an identification of the alternative control methods, and an estimate of yield and cost changes caused by switching to the alternatives. Data for benefit assessment are generally scarce. USDA estimates of pesticides used on such major field crops as corn, soybeans, cotton, and wheat are often available, but not for many fruits and vegetables. In the latter cases, crop and pest control experts must subjectively estimate pesticide use, alternative controls, and the extent of their use. From these estimates, cost changes can be derived. The changes in yield are another matter. In some cases, yield differences could be derived from field tests. But, such tests are often scarce, and their results might not be representative for the entire area where the pesticide is used (9). Thus, expert estimates are often necessary to obtain yield differences.

Pesticide regulations cause distributional effects where different groups of people experience varying degrees of gains or losses. In fact, there can be transfers between farmers and consumers and different groups of farmers whereby some parties gain and others lose. Traditional analyses estimated net efficiency loss. However, fairness or equity is a major issue, and some people could argue that the distributional effects of a decision are fair while others disagree. Computing efficiency and distributional effects of pesticide regulatory actions and including them in regulatory decisions is an often-debated subject.

Estimating the benefits and distributional effects from the cost and yield change estimates often depends on the economic methods used. Many assessments, such as those of dimethoate and 2,4,5-T, addressed these effects through partial budgeting (79, 80). This method equates the benefits of a pesticide to the value of production lost plus the change in control costs caused by switching to alternative control methods. If the assumption of constant price is correct, the method accurately assesses social loss that is borne entirely by the users of the pesticides and by farmers suffering yield losses (generally assumed to be the same people).

However, the estimates of partial budgeting methods become less accurate when production losses are large enough to induce significant price changes. Production losses or cost increases, or both, can cause demand-induced price increases for crops treated with the pesticide, which, in turn, influence farmers' planting decisions. As a result of higher price and lower quantity, consumers pay some of the cost of a pesticide ban. If quantity demanded is not significantly affected by price (that is, demand is sufficiently price inelastic), farm income could actually increase. Yield, cost, and price changes can encourage farmers to change the areas planted to alternative crops, thereby affecting the prices and production of crops not directly affected by the regulation. Recent studies have used large econometric or mathematical programming models to account for simultaneous price, acreage, consumer, and producer effects for several crops (5, 58, 71, 84). Typical results are increased prices for crops treated with the banned pesticide and crops that can be substituted in production or consumption, while producers gain and consumers lose. The effects of the regulation thus spread through the economy with a variety of distributional effects.

EPA has argued, to help justify restriction or cancellation of a pesticide's registration, that higher prices increase farm income, but increased food costs will be spread over many consumers with little effect on any one person (82). However, there are distributional effects in addition to those between consumers and producers that are not often considered in benefits assessments. Farmers who do not use a pesticide under review would gain from higher crop prices, but farmers who do use the pesticide might lose (4, 16, 57, 58, 65). Regions where use of the pesticide was concentrated could suffer economic losses (59). Banning a pesticide with small aggregate effects could cause a severe financial loss for a small number of highly dependent farmers. Society might view such outcomes as unfair and wish to keep some pesticides with small aggregate benefits on the market or compensate the users for their losses.

Lichtenberg and Zilberman recently argued that regulations which reduce production must also account for the effect on farm program payments as well as on consumers and producers (48). If farm programs encourage overproduction of program crops, pesticide regulations that restrict input use and thereby reduce production and inventories will reduce program payments. The reduction in payments, according to this argument, is a benefit of the regulation. According to their argument, not accounting for reductions in program payments results in an overestimate of pesticide benefits. The argument implies that consumers suffer no losses while farmers lose because of reduced payments.

Lichtenberg and Zilberman's argument, however, ignores another view: society deliberately bears an economic loss to transfer income from consumers to support farm income at a level that free markets would not (27). If that income transfer is not desirable, changing the farm programs (by reducing or eliminating target prices, for example) might reduce program payments more efficiently than banning pesticides would. Reducing or eliminating target prices would reduce social losses caused by overproducing agricultural commodities and would encourage a reallocation of resources to other purposes. Cost per unit of output would also be less than if pesticides were banned. However, if the income transfer is desirable, the pesticide ban would reduce the income support to users of the banned pesticide (59). If society wished to prevent such user losses, the losers could be compensated or the pesticide registration retained.

Implications of Alternative Pesticides

A critical determinant of pesticide benefits is the availability of chemical or nonchemical alternatives to control the pest(s) for which the chemical is used. If alternatives are nonexistent, ineffective, or too expensive, the pesticide can have substantial benefits. Thus, EPA has retained the registration of several pesticides without effective alternatives but with sufficient risk for continued EPA concern (87). Lindane and dimethoate are examples. As the substitutability or the cost-effectiveness of alternatives increases, however, the benefits of the pesticide in question decrease. Thus, the presence of cost-effective alternatives may be sufficient reason to remove a pesticide with health or environmental risk concerns from the market.

When there are several cost-effective alternatives, the economic benefits of controlling a pest are much greater than the benefits of any individual pesticide. Osteen and Kuchler compared the economic effects of banning one or two corn and soybean pesticides versus banning all alternatives for the pest (table 20, 58). (Amides and triazines are herbicide families; the members of each family control similar, but not identical, spectra of weed species.) In every case, the economic effects of banning a group of pesticides is much greater than the effects of banning the single pesticide. The benefits of controlling the pest are reduced by the small benefits of each alternative banned and are concentrated on a smaller number of pesticides. Consequently, the benefits of the last available pesticide are relatively great.

Regulatory decisions are interdependent because the benefits of a pesticide depend upon previous decisions. Interactions in chemical use for such purposes as managing resistance can also create an interdependence (59). Carlson stated

Table 20--Aggregate effects of corn and soybean pesticide bans

Pesticide or pesticide group	Producer gain	Consumer loss	Net loss 1/
		Million dollars	
Isofenfos and terbufos	70.3	96.6	26.3
Soil insecticides	5,984.0	8,132.2	2,148.2
Difference 2/	5,913.7	8,035.6	2,121.9
Permethrin	284.6	351.7	67.1
Foliar insecticides	3,200.1	3,877.2	677.1
Difference 2/	2,915.5	3,525.5	610.0
Captan	112.2	183.6	71.4
Seed treatments	3,566.6	4,717.1	1,150.5
Difference 2/	3,454.4	4,533.5	1,079.1
Benomyl	318.1	394.3	76.2
Foliar fungicides	729.9	857.4	127.5
Difference 2/	411.8	463.1	51.3
Alachlor	186.2	335.0	148.8
Amides	4,935.0	7,059.6	2,124.6
Difference 2/	4,748.8	6,724.6	1,975.8
Atrazine	1,126.6	1,906.4	779.9
Metribuzin	694.3	855.4	161.1
Triazines	5,411.1	8,761.2	3,350.1
Difference (Atrazine) 3/	4,284.6	6,854.8	2,570.2
Difference (Metribuzin) 3/	4,716.8	7,905.8	3,189.0

1/ Difference between producer gain and consumer loss.
2/ Second row minus first row.
3/ Difference between chemical in parentheses and triazines.

that pesticide cancellations may have encouraged resistance by increasing selective pressure from the remaining alternatives (8).

The interdependence of regulatory decisions exists for both benefits and risks. EPA assesses risk from and exposure to the chemical in question but, at least in the past, has not usually assessed the resulting risk and exposure as farmers switch to alternative chemicals. Thus, absolute risk is weighed against comparative benefits. Because risk data are scarce for many pesticides, an alternative pesticide might pose greater risk than the one assessed. Large numbers of pesticides registered before 1972 have incomplete risk information, and roughly half the pesticide registrations between 1978 and 1984 were granted conditionally with incomplete information (87). Special Reviews need only address the risk criteria that current data indicate to be a problem, even if data for other criteria are not available (87). Alternative chemicals could increase risks in dimensions not examined under Special Review. EPA apparently recognizes that banning a pesticide may increase the use of riskier alternatives.

Some pesticide bans might ultimately increase health and safety risks while reducing the efficiency of crop production, an undesirable outcome from almost any viewpoint. A pesticide ban could be more likely to reduce rather than increase risk. But will risk be reduced enough, after switching to alternatives, to justify the production efficiency losses or equity effects or both? If changes in risk were estimated, some pesticide registrations might be retained rather than cancelled.

The lack of data and the difficulty of precisely estimating the extent of exposure and the risk of health, safety, or environmental effects maintain an important controversy surrounding agricultural chemical use. Increased sophistication of testing devices allows the ability to detect chemicals present in water and food products that were undetectable just a few years ago. The question becomes what level of exposure to health or environmental risks from agricultural chemicals is acceptable? How do we measure total exposure from all toxicity sources and arrive at an acceptable exposure norm?

The interdependence of regulatory decisions, for both risks and benefits, creates a potentially significant dilemma. EPA might find that one of the remaining alternatives has greater risks than previously banned pesticides, but that also has substantial benefits because few or no effective alternatives are available. A better choice may have been to leave a previously banned pesticide on the market and ban the one under examination. Accelerating reregistration and Special Review processes under recently passed FIFRA amendments could force simultaneous, but independent, assessments of alternatives and aggravate the dilemma. Conversely, delaying a decision until all risk data from alternatives are available might still result in a ban while society suffers the risk in the interim.

The sequence of pesticides assessed could substantially influence economic efficiency, income distribution, and risks borne by society over time. EPA needs to review the riskiest pesticides first to reduce the possibility that a pesticide ban increases risk (53). EPA should ideally examine the risks of alternatives to the chemical under review. EPA might also simultaneously examine risks and benefits of all alternatives used for a pest problem and determine an optimal strategy, before deciding the fate of any single chemical.

Summary

Agricultural pesticide use has increased dramatically since World War II. Pesticide use has been an integral part of technological advances that reduced agricultural labor use by almost 75 percent and increased productivity by 230 percent. Pesticides' share of operating expenditures grew from 0.7 percent in 1945 to 5.9 percent in 1986, while labor's share fell from 24 percent to 14 percent.

Pesticide use on major crops increased from 225 million pounds a.i. in 1964 to 558 million pounds a.i. in 1982, led by strong growth in herbicide use. Farmers applied herbicides to less than 10 percent of corn, cotton, and wheat acreage in 1952, but treated 90-95 percent by 1980. Since 1980, pesticide use has stabilized or even decreased. Aggregate pesticide use has been heavily influenced by planted acreage. Acreage diversion, particularly the 1983 Payment-in-Kind Program, has contributed to decreases in pesticide use. Thus, assessing benefits of pesticide use or hazards to human health and the environment is difficult.

The use of pesticides in corn and soybean production has grown dramatically. Corn and soybean insecticide use increased from 21 million pounds a.i. in 1964 to 41 million pounds a.i. in 1982, but cotton insecticide use decreased from 78 million pounds a.i. in 1964 to 17 million pounds a.i. in 1982. Corn and soybean herbicide use increased from 30 million pounds a.i. in 1964 to 370 million pounds a.i. in 1982. Thus, total pesticide use on major crops grew faster in the Corn Belt and Lake States than in other regions during that period.

Pesticide use data to show time trends are scarce. USDA/ERS conducted national pesticide surveys in 1964, 1966, 1971, 1976, and 1982. However, the area and crop coverage have decreased over time as costs increased. Many individual crop surveys, particularly on major field crops, have been conducted since the late 1970's. However, no USDA pesticide use data for fruits, vegetables, or livestock are available after 1979.

Economic research shows returns to pesticide use generally exceed costs, but more recent studies often estimate lower returns than earlier studies, suggesting that pesticide use is reaching an economic optimum or that earlier specifications overestimated returns. Moreover, pesticide benefit assessments usually show cost increases or yield declines, or both, if specific pesticides are removed from the market. The combination of price supports and acreage diversions are alleged to have encouraged more pesticide use per acre than free markets would. Commodity programs and farm policy are plausible explanations for some of the growth in pesticide use, but casual observation of the scarce data does not invalidate the argument that growth is due to pesticide cost-effectiveness. However, the administrative freeze of farm program yields under the Food Security Act of 1985 should terminate the effect of target prices on per acre pesticide use.

Pesticides provide many economic benefits, but there are many concerns about toxicity to humans, chronic health effects, food safety, surface and ground water pollution, and wildlife mortality. During the 1970's, the pesticide regulatory process changed from emphasizing consumer protection from ineffective products to emphasizing protection from potential health, safety, and environmental effects of pesticide use. The pesticide regulatory process provides for the removal of pesticides from the market if risks outweigh the economic benefits.

The economic effects of removing a pesticide from the market depend upon the yield, product quality, and cost changes of switching to alternative pesticides. If cost-effective alternatives are available, the benefits of a pesticide will be low. If alternatives are ineffective, expensive, or unavailable, the benefits can be very high. If prices change as a result, consumers may have higher food costs due to higher prices, and users of the regulated pesticide may lose income because of yield losses. However, producers not affected by the pesticide decision may gain income from higher prices. Regions that depend heavily on a banned pesticide may lose while other regions gain.

The benefits of an individual pesticide may be small, but the benefits of controlling a pest may be high. Successively removing alternative pesticides concentrates the benefits on a smaller number of materials until benefits become large. Alternative pesticides may also have risks. Thus, if the highest risk pesticides are not examined first, risks could actually increase once a pesticide is removed from the market. Such a decision could result in greater risks and a loss of economic benefits.

Resistance, regulatory activity, and innovation of more effective pesticides have contributed to a change in pesticide product mix over time. For example, pyrethroid, carbamate, and organophosphate pesticides have replaced organochlorines. Pyrethroids have significantly reduced application rates per treatment on cotton. Pest resistance and regulatory actions caused by concerns about the environmental effects of organochlorines have contributed to the decline in their use. Extensive EPA regulatory activity from 1972 to 1980 may have contributed to the change in product mix, but apparently did not slow the growth of pesticide use during that period. Concerns about the counterproductive effects of overuse, such as resistance and the mortality of natural pest enemies and beneficial species, led to the development of economic thresholds and integrated pest management. These concepts have been applied to cotton and fruit production, and they may have changed the mix of pesticides used and reduced the number of applications.

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Appendix Tables

Appendix table 1--Insecticide use on selected crops

Item	1964	1966	1971	1976	1977	1978	1979	1980	1982
					Million pounds (a.i.)				
Major crops:									
Corn	15.7	23.6	25.5	32.0	NA	NA	NA	36.4	30.1
Cotton	78.0	64.9	73.4	64.1	NA	NA	22.0	NA	16.9
Wheat	1/	.9	1.7	7.2	NA	NA	NA	NA	2.6
Sorghum	1/	.8	5.7	4.6	NA	NA	NA	3.0	2.6
Rice	1/	.3	1.0	.5	NA	NA	NA	NA	.6
Other grains	1/	.3	.8	1.8	NA	NA	NA	NA	.2
Soybeans	5.0	3.2	5.6	7.9	NA	NA	NA	8.0	11.1
Tobacco	5.5	3.8	4.0	3.3	NA	NA	NA	NA	3.5
Peanuts	1/	5.5	6.0	2.4	NA	NA	NA	NA	1.0
Hay and pasture	1/	4.1	2.6	6.5	NA	NA	NA	NA	2.6
Other field crops	12.5	.8	1.6	NA	NA	NA	NA	NA	NA
Total, major crops	116.7	108.2	127.9	130.3	NA	NA	NA	NA	71.2
Other crops:									
Potatoes	1.5	3.0	2.8	NA	NA	NA	3.3	NA	NA
Other vegetables	8.3	8.2	8.3	NA	NA	NA	4.2	NA	NA
Citrus fruits	1.4	2.9	3.1	NA	27.8	NA	NA	NA	NA
Apples	10.8	8.5	4.8	NA	NA	3.0	NA	NA	NA
Grapes	NA	NA	NA	NA	NA	NA	.1	NA	NA
Other fruits	4.5	6.6	6.3	NA	NA	1.1	NA	NA	NA
Total, fruits and vegetables	26.5	29.2	25.3	NA	NA	NA	NA	NA	NA
Sugar beets	NA	.1	.6	NA	NA	NA	NA	NA	NA
Petroleum	2/	11.2	60.7	NA	NA	17.0	NA	NA	NA

NA = Not available.
1/ Summarized under other field crops.
2/ Summarized in app. table 5.

Appendix table 2--Herbicide use on selected crops

Item	1964	1966	1971	1976	1977	1978	1979	1980	1982
				Million pounds (a.i.)					
Major crops:									
Corn	25.5	46.0	101.1	207.1	NA	NA	NA	209.5	243.4
Cotton	4.6	6.5	19.6	18.3	NA	NA	18.6	NA	18.3
Wheat	9.2	8.3	11.6	21.9	NA	NA	NA	NA	18.1
Sorghum	2.0	4.0	11.5	15.7	NA	NA	NA	11.8	15.7
Rice	1/	2.8	8.0	8.5	NA	NA	NA	NA	14.1
Other grains	9.1	4.9	5.4	5.5	NA	NA	NA	NA	5.9
Soybeans	4.2	10.4	36.5	81.1	NA	NA	NA	114.4	127.0
Tobacco	1/	1/	.2	1.2	NA	NA	NA	NA	1.5
Peanuts	1/	2.9	4.4	3.4	NA	NA	NA	NA	4.9
Hay and pasture	4.7	11.8	9.0	11.2	NA	NA	NA	NA	6.7
Other field crops	11.2	3.6	5.8	NA	NA	NA	NA	NA	NA
Total, major crops	70.5	101.2	213.1	373.9	NA	NA	NA	NA	455.6
Other crops:									
Potatoes	2/	2.2	2.2	NA	NA	NA	1.4	NA	NA
Other vegetables	2/	3.5	3.4	NA	NA	NA	4.0	NA	NA
Citrus fruits	2/	.4	.6	NA	5.5	NA	NA	NA	NA
Apples	2/	.4	.2	NA	NA	.7	NA	NA	NA
Grapes	2/	NA	NA	NA	NA	NA	.1	NA	NA
Other fruits	2/	2.8	1.5	NA	NA	.1	NA	NA	NA
Total, fruits and vegetables	5.8	9.3	7.9	NA	NA	NA	NA	NA	NA
Sugar beets	NA	.9	3.0	NA	NA	NA	NA	NA	NA
Petroleum	3/	67.6	142.8	NA	NA	.9	NA	NA	NA

NA = Not available.

1/ Summarized under other field crops.

2/ Summarized under fruits and vegetables.

3/ Summarized in app. table 5.

Appendix table 3--Fungicide use on selected crops

Item	1964	1966	1971	1976	1977	1978	1979	1980	1982
					Million pounds (a.i.)				
Major crops:									
Corn	1/	1/	1/	NA	NA	NA	NA	NA	0.1
Cotton	.2	.4	.2	NA	NA	NA	NA	NA	.2
Sulfur	10.2	1/	15.1	NA	NA	NA	NA	NA	NA
Wheat	1/	1/	1/	.9	NA	NA	NA	NA	1.0
Sorghum	1/	1/	1/	2/	NA	NA	NA	NA	*
Rice	1/	1/	1/	2/	NA	NA	NA	NA	*
Other grains	1/	1/	1/	2/	NA	NA	NA	NA	*
Soybeans	1/	1/	1/	.2	NA	NA	NA	NA	.1
Tobacco	1/	1/	*	.2	NA	NA	NA	NA	.5
Peanuts	1/	1.1	4.4	6.8	NA	NA	NA	NA	4.7
Sulfur	NA	15.4	26	NA	NA	NA	NA	NA	NA
Other field crops	5.6	4.5	1.8	2/	NA	NA	NA	NA	*
Sulfur	52.8	*	.8	NA	NA	NA	NA	NA	NA
Total, major crops	5.8	6.0	6.4	8.1	NA	NA	NA	NA	6.6
Sulfur	63.0	16.4	41.9	NA	NA	NA	NA	NA	NA
Other crops:									
Potatoes	3.7	3.5	4.1	NA	NA	NA	3.9	NA	NA
Other vegetables	4.5	4.1	5.7	NA	NA	NA	4.8	NA	NA
Sulfur	2.5	1.1	5.2	NA	NA	NA	NA	NA	NA
Citrus fruits	5.0	4.1	9.3	NA	5.0	NA	NA	NA	NA
Sulfur	18.2	14.4	24.5	NA	.2	NA	NA	NA	NA
Apples	7.8	8.5	7.2	NA	NA	5.9	NA	NA	NA
Sulfur	9.6	4.8	1.1	NA	NA	1.5	NA	NA	NA
Grapes (NY/PA)	NA	NA	NA	NA	NA	NA	.2	NA	NA
Other fruits	3.9	4.3	6.9	NA	NA	1.3	NA	NA	NA
Sulfur	41.8	20.0	39.3	NA	NA	4.3	NA	NA	NA
Total, fruits and vegetables	24.9	24.5	33.2	NA	NA	NA	NA	NA	NA
Sulfur	72.1	40.3	70.1	NA	NA	NA	NA	NA	NA

NA = Not available.
* = Insignificant quantity.
1/ Summarized under other field crops.
2/ Summarized under total, major field crops.

Appendix table 4--Use of other pesticides on selected crops

Item	1964	1966	1971	1976	1977	1978	1979	1980	1982
					Million pounds (a.i.)				
Major crops:									
Corn	0.1	0.5	0.4	0.5	NA	NA	NA	NA	0.1
Cotton	12.4	14.2	18.7	12.7	NA	NA	23.2	NA	8.2
Wheat	1/	1/	.2	*	NA	NA	NA	NA	*
Sorghum	1/	1/	1/	.3	NA	NA	NA	NA	.1
Rice	1/	1/	1/	*	NA	NA	NA	NA	*
Other grains	1/	1/	1/	*	NA	NA	NA	NA	*
Soybeans	1/	1/	.1	2.0	NA	NA	NA	NA	2.3
Tobacco	17.6	13.4	9.4	18.5	NA	NA	NA	NA	12.0
Peanuts	1/	7.0	.5	1.2	NA	NA	NA	NA	1.6
Hay and pasture	1/	.3	1/	.1	NA	NA	NA	NA	NA
Other field crops	1.6	.3	.5	*	NA	NA	NA	NA	NA
Total, major crops	31.7	35.7	29.8	35.3	NA	NA	NA	NA	24.3
Other crops:									
Potatoes	.1	2/	2/	NA	NA	NA	6.7	NA	NA
Other vegetables	5.8	2/	2/	NA	NA	NA	3.1	NA	NA
Citrus fruits	1.5	1.1	1.3	NA	NA	NA	NA	NA	NA
Apples	1.0	1.1	.5	NA	NA	.6	NA	NA	NA
Other fruits	1.1	8.7	1.8	NA	NA	.1	NA	NA	NA
Total, fruits and vegetables	9.5	11.8	14.1	NA	NA	NA	NA	NA	NA
Sugar beets	NA	.1	2.1	NA	NA	NA	NA	NA	NA

NA = Not available.
* = Insignificant quantity.
1/ Summarized under other field crops.
2/ Summarized under total, fruits and vegetables.

Appendix table 5--Total pesticide use on selected crops

Item	1964	1966	1971	1976	1977	1978	1979	1980	1982
					Million pounds (a.i.)				
Major crops:									
Corn	1/	1/	1/	239.6	NA	NA	NA	245.9	273.7
Cotton	95.2	86.0	111.9	95.1	NA	NA	63.8	NA	43.6
Wheat	1/	1/	1/	30.0	NA	NA	NA	NA	21.7
Sorghum	1/	1/	1/	20.6	NA	NA	NA	14.8	18.4
Rice	1/	1/	1/	9.0	NA	NA	NA	NA	14.7
Other grains	1/	1/	1/	7.3	NA	NA	NA	NA	6.1
Soybeans	1/	1/	1/	91.2	NA	NA	NA	122.4	140.5
Tobacco	1/	1/	13.6	23.2	NA	NA	NA	NA	17.5
Peanuts	1/	16.5	15.3	13.8	NA	NA	NA	NA	12.2
Hay and pasture	4.7	16.2	1/	17.8	NA	NA	NA	NA	9.3
Other field crops	124.8	132.4	236.4	NA	NA	NA	NA	NA	NA
Total, major crops	224.7	251.1	377.2	547.6	NA	NA	NA	NA	557.7
Other crops:									
Potatoes	2/	3/	3/	NA	NA	NA	15.3	NA	NA
Other vegetables	2/	3/	3/	NA	NA	NA	16.1	NA	NA
Total, vegetables	2/	25.3	36.9	NA	NA	NA	NA	NA	NA
Citrus fruits	2/	8.5	14.2	NA	38.3	NA	NA	NA	NA
Apples	2/	18.5	12.7	NA	NA	10.2	NA	NA	NA
Grapes	2/	NA	NA	NA	NA	NA	.4	NA	NA
Other fruits	2/	22.4	16.5	NA	NA	2.6	NA	NA	NA
Total, fruits and vegetables	66.7	74.7	80.3	NA	NA	NA	NA	NA	NA
Sugar beets	NA	1.1	5.7	NA	NA	NA	NA	NA	NA
Petroleum	232.6	78.8	203.5	NA	NA	NA	NA	NA	NA
Sulfur	135.1	56.7	112.0	NA	NA	NA	NA	NA	NA

NA = Not available.
1/ Summarized under other field crops.
2/ Summarized under total, fruits and vegetables.
3/ Summarized under total, vegetables.

Appendix table 6--Insecticide use on selected crops, by regions, 1964 1/

Crop	North-east	Lake	Corn Belt	Northern Plains	Appa-lachia	South-east	Delta	Southern Plains	Mountain	Pacific	Total
					1,000 pounds (a.i.)						
Corn	50	887	10,812	2,532	1,053	194	2/	17	113	2/	15,668
Cotton	---	---	418	---	4,999	23,774	23,530	20,797	2,253	2,251	78,022
Soybeans	24	2/	516	2/	369	1,348	2,729	2/	---	---	4,997
Tobacco	119	2/	34	---	3,042	2,273	---	---	---	---	5,471
Other field crops 3/	433	195	945	109	2,400	4,504	629	760	679	1,897	12,551
Potatoes	284	315	107	110	19	59	---	---	142	420	1,456
Other vegetables	2,272	127	653	---	287	1,479	59	173	423	2,817	8,290
Citrus fruits	---	---	---	---	---	967	---	51	---	407	1,425
Apples	3,413	1,672	765	---	1,591	---	37	---	239	3,111	10,828
Other fruit	353	573	108	---	16	438	79	326	81	2,502	4,476
Total	6,948	3,779	14,358	2,754	13,776	35,036	27,068	22,126	3,930	13,409	143,184

--- = None reported.
1/ Excludes Alaska and Hawaii; excludes petroleum.
2/ Less than 10,000 pounds used.
3/ Includes wheat, sorghum, barley, rye, rice, mixed grains, all hay (including alfalfa), pasture, and other field crops.

Appendix table 7--Herbicide use on selected crops, by regions, 1964 1/

Crop	North-east	Lake	Corn Belt	Northern Plains	Appa-lachia	South-east	Delta	Southern Plains	Mountain	Pacific	Total
					1,000 pounds (a.i.)						
Corn	2,487	5,311	12,590	1,960	1,937	502	192	22	388	87	25,476
Cotton	---	---	80	---	479	586	2,465	985	2/	29	4,628
Wheat	---	252	11	2,877	21	2/	2/	43	2,932	3,032	9,178
Sorghum	---	2/	54	1,001	26	29	---	406	440	2/	1,966
Other grains 3/	400	778	137	1,311	18	18	1,431	2,913	862	1,251	9,119
Soybeans	242	272	3,024	58	225	15	372	---	---	---	4,208
Other field crops 4/	1,509	766	212	864	1,699	1,332	2/	29	3,443	1,344	11,206
Hay and pasture	15	150	740	878	246	388	342	1,733	96	99	4,687
Fruits and vegetables 5/	3,005	610	147	216	22	317	25	---	313	1,191	5,846
Total	7,658	8,141	16,995	9,165	4,673	3,195	4,837	6,131	8,478	7,041	76,314

--- = None reported.
1/ Excludes Alaska and Hawaii; excludes petroleum.
2/ Less than 10,000 pounds used.
3/ Includes barley, rye, rice, oats, and mixed grains.
4/ Includes tobacco and other crops.
5/ Includes potatoes and all other vegetables and fruits.

Appendix table 8--Fungicide use on selected crops, by regions, 1964 1/

Crop	North-east	Lake	Corn Belt	Northern Plains	Appa-lachia	South-east	Delta	Southern Plains	Mountain	Pacific	Total
						1,000 pounds (a.i.)					
Corn	131	---	74	91	29	---	---	---	218	---	543
Cotton	---	---	---	---	27	1,234	61	5,164	178	3,752	10,416
Soybeans	52	---	241	---	---	979	---	---	---	---	1,272
Tobacco	20	---	---	---	1,912	468	---	---	---	---	2,400
Other field crops 2/	136	178	727	218	13,774	39,168	---	---	13	---	54,214
Potatoes	1,921	753	202	---	3/	77	---	---	71	691	3,719
Other vegetables	812	235	1,082	---	65	2,524	3/	342	250	1,677	6,993
Citrus fruits	---	---	---	---	---	20,727	---	37	---	2,405	23,169
Apples	3,543	1,504	5,204	---	4,750	---	53	---	387	1,916	17,357
Other deciduous fruits	1,359	1,585	639	---	56	7,650	---	454	122	5,237	17,102
Other fruit	64	77	12	---	3/	38	105	28	---	28,433	28,758
Total fungicides, including sulfur	8,038	4,332	8,181	309	20,618	72,865	225	6,025	1,239	44,111	165,943
Sulfur	1,520	2,182	4,462	105	15,137	64,536	24	5,823	1,031	40,408	135,228
Total fungicides, excluding sulfur	6,518	2,150	3,719	204	5,481	8,329	201	202	208	3,703	30,715

--- = None reported.
1/ Excludes Alaska and Hawaii; excludes petroleum but includes sulfur.
2/ Includes sorghum, other grain, alfalfa, other hay, and pasture.
3/ Less than 10,000 pounds used.

Appendix table 9--Use of other pesticides on selected crops, by regions, 1964 1/

Crop	North-east	Lake	Corn Belt	Northern Plains	Appa-lachia	South-east	Delta	Southern Plains	Mountain	Pacific	Total
					1,000 pounds (a.i.)						
Corn	---	---	10	2/	43	---	2/	---	---	10	76
Cotton	---	---	69	---	124	1,019	2,143	6,198	18	2,860	12,431
Tobacco	58	---	---	---	14,470	3,023	---	---	---	---	17,551
Other field crops 3/	---	---	---	54	171	---	43	---	1,286	57	1,611
Potatoes	2/	---	2/	---	66	---	---	---	18	---	91
Other vegetables	138	43	12	---	2/	4,193	---	---	44	1,380	5,819
Citrus fruits	---	---	---	---	---	1,362	---	2/	---	176	1,539
Apples	149	130	149	---	45	---	---	---	47	517	1,037
Other fruit	22	10	2/	---	---	---	---	---	2/	1,004	1,041
Total	370	183	246	59	14,928	9,597	2,194	6,199	1,416	6,004	41,196

--- = None reported.

1/ Includes miticides, fumigants, desiccants and defoliants, rodenticides, plant growth regulators, and repellents; excludes Alaska and Hawaii; excludes petroleum.

2/ Less than 10,000 pounds used.

3/ Includes sorghum, soybeans, hay and pasture (including alfalfa), summer fallow, and other field crops.

Appendix table 10--Insecticide use on selected crops, by regions, 1966 1/

Crop	North-east	Lake	Corn Belt	Northern Plains	Appa-lachia	South-east	Delta	Southern Plains	Mountain	Pacific	Total
						1,000 pounds (a.i.)					
Corn	92	1,601	17,525	3,660	346	99	16	2/	186	102	23,629
Cotton	---	---	205	---	3,302	22,603	20,799	12,551	4,357	1,083	64,900
Wheat	---	2/	77	228	203	---	2/	353	2/	---	876
Sorghum	---	---	40	34	---	355	90	236	12	---	767
Rice	---	---	---	---	---	---	23	289	---	---	312
Other grains 3/	2/	52	2/	77	46	---	2/	84	2/	---	273
Soybeans	22	---	244	2/	809	1,903	199	33	---	---	3,217
Tobacco	92	2/	13	---	2,479	1,206	---	---	---	---	3,791
Peanuts	---	---	---	---	1,051	4,478	---	---	---	---	5,529
Other field crops	27	70	56	37	55	61	217	12	120	149	804
Alfalfa	788	3	114	286	752	---	2/	278	1,265	119	3,607
Other hay crops and forage	99	---	12	---	13	14	2/	2/	---	---	145
Pasture and rangeland	---	2/	2/	2/	2/	118	2/	38	163	---	342
Sugar beets	2/	---	---	20	---	---	---	---	59	31	112
Potatoes	933	590	204	144	37	21	---	2/	415	626	2,972
Other vegetables	875	263	558	2/	299	1,202	188	1,780	114	2,880	8,163
Citrus fruits	---	---	---	---	---	2,335	---	116	---	407	2,858
Apples	3,116	1,231	2,134	---	1,129	---	---	2/	125	757	8,494
Other deciduous fruits	730	614	160	---	188	727	19	200	82	1,358	4,078
Other fruits and nuts	198	128	81	---	13	312	209	---	---	1,600	2,541
Nursery and greenhouse	2/	14	26	---	24	---	20	---	---	38	128
Other	---	19	4	---	---	---	---	---	4	1	28
Total	6,984	4,591	21,457	4,502	10,750	35,434	21,807	15,981	6,909	9,151	137,566

--- = None reported.

1/ Excludes Alaska and Hawaii; excludes petroleum.

2/ Less than 10,000 pounds.

3/ Barley, oats, rye, and mixed grains.

Appendix table 11--Herbicide use on selected crops, by regions, 1966 1/

Crop	Northeast	Lake	Corn Belt	Northern Plains	Appalachia	Southeast	Delta	Southern Plains	Mountain	Pacific	Total
						1,000 pounds (a.i.)					
Corn	2,846	7,427	27,473	3,361	3,182	741	174	95	362	309	45,970
Cotton	---	---	146	---	331	1,066	2,419	1,415	308	841	6,526
Wheat	---	231	47	3,093	16	2/	---	26	1,874	2,954	8,247
Sorghum	2/	---	270	1,922	93	33	68	1,346	199	99	4,031
Rice	---	---	---	---	---	---	1,536	1,283	---	---	2,819
Other grains	175	891	95	1767	2/	2/	---	77	927	984	4,921
Soybeans	88	1,135	6,567	283	532	374	1,407	23	---	---	10,409
Peanuts	---	---	---	---	553	2,339	---	2/	2/	---	2,899
Other field crops 3/	77	1,013	276	551	98	2/	155	2/	280	1,152	3,613
Alfalfa, other hay, and forage	19	2/	2/	648	18	15	---	176	12	386	1,291
Pasture and rangeland	2/	68	191	2,845	305	15	143	3,027	1,836	2,072	10,506
Sugar beets	---	250	53	216	---	---	---	---	244	146	909
Potatoes	1,833	85	159	---	---	15	---	---	24	104	2,220
Other vegetables	936	362	95	---	30	22	114	64	174	1,691	3,488
Citrus fruits	---	---	---	---	---	288	---	---	---	65	353
Apples	117	25	47	---	84	---	---	---	13	103	389
All other fruits and nuts	112	48	10	---	2/	2/	49	---	2/	2,625	2,856
Summer fallow	---	45	15	191	---	2/	41	2/	46	520	865
Nursery and greenhouse	2/	---	27	---	---	---	---	---	---	79	108
Total	6,210	11,588	35,480	14,877	5,245	4,933	6,106	7,547	6,304	14,130	112,420

--- = None reported.
1/ Excludes Alaska and Hawaii; excludes petroleum.
2/ Less than 10,000 pounds.
3/ Includes tobacco and other field crops.

Appendix table 12--Fungicide use on selected crops, by regions, 1966 1/

Crop	North-east	Lake	Corn Belt	Northern Plains	Appa-lachia	South-east	Delta	Southern Plains	Mountain	Pacific	Total
						1,000 pounds (a.i.)					
Cotton	---	---	2/	---	2/	48	19	36	---	266	376
Peanuts	---	---	---	---	623	485	---	---	---	---	1,108
Potatoes	2,396	254	173	564	---	2/	---	---	37	98	3,531
Other vegetables	577	250	1,218	---	13	1,082	---	487	82	384	4,093
Citrus fruits	---	---	---	---	---	3,414	---	636	---	2/	4,056
Apples	3,093	1,992	741	---	2,399	---	---	---	33	238	8,496
Other deciduous fruits	464	551	42	---	---	130	2/	---	187	426	1,804
Other fruits and nuts	265	239	---	---	149	36	572	---	---	1,237	2,498
All other crops 3/	28	111	3,194	248	153	19	---	597	15	163	4,528
Total	6,823	3,397	5,372	812	3,340	5,223	595	1,756	354	2,818	30,490

--- = None reported.

1/ Excludes Alaska and Hawaii; excludes sulfur.

2/ Less than 10,000 pounds.

3/ Includes corn, sorghum, wheat, rice, tobacco, soybeans, sugar beets, other grains, other field crops, and other hay and pasture.

Appendix table 13--Use of other pesticides on selected crops, by regions, 1966 1/

Crop	North-east	Lake	Corn Belt	Northern Plains	Appa-lachia	South-east	Delta	Southern Plains	Mountain	Pacific	Total
					1,000 pounds (a.i.)						
Corn	2/	163	112	113	44	---	2/	---	15	87	546
Cotton	---	---	83	---	202	830	1,591	2,100	404	8,997	14,207
Wheat	---	---	---	---	---	---	---	18	---	29	47
Sorghum	---	---	---	---	---	---	---	14	26	---	40
Soybeans	---	---	---	---	49	---	---	---	---	---	49
Tobacco	94	---	40	---	8,963	4,304	---	---	---	---	13,401
Peanuts	---	---	---	---	1,594	5,411	---	---	---	---	7,005
Other field crops	---	---	---	---	---	---	---	---	26	57	83
Alfalfa	2/	---	---	---	---	---	---	68	---	277	348
Sugar beets	---	---	---	---	---	---	---	---	70	---	70
Potatoes and vegetables	183	105	106	---	200	206	---	---	13	51	864
Citrus fruits	---	---	---	---	---	411	---	---	---	712	1,123
Apples	361	247	92	---	42	---	---	---	222	155	1,119
Other deciduous fruits	14	91	264	---	---	---	---	---	16	266	651
Other fruits and nuts	---	2/	---	---	---	2/	---	---	---	8,035	8,041
Nursery, greenhouse, and other	2/	2/	58	---	---	---	2/	---	---	2/	69
Total	665	611	755	113	11,094	11,164	1,601	2,200	792	18,668	47,663

--- = None reported.

1/ Includes miticides, fumigants, desiccants and defoliants, rodenticides, plant growth regulators, and repellents; excludes Alaska and Hawaii; excludes petroleum.

2/ Less than 10,000 pounds.

Appendix table 14--Insecticide use on selected crops, by regions, 1971 1/

Crop	North-east	Lake	Corn Belt	Northern Plains	Appa-lachia	South-east	Delta	Southern Plains	Mountain	Pacific	Total
					1,000 pounds (a.i.)						
Corn	155	2,749	15,314	5,852	375	42	37	54	928	25	25,531
Cotton	---	---	38	---	3,610	27,259	29,323	10,320	1,868	939	73,357
Wheat	2/	---	---	41	2/	2/	87	1,355	33	193	1,712
Sorghum	---	---	94	1,301	28	406	339	2,927	398	236	5,729
Rice	---	---	---	---	---	---	91	726	---	129	946
Other grains 3/	14	181	112	2/	10	2/	36	404	2/	59	821
Soybeans	27	---	117	---	928	2,655	1,872	22	---	---	5,621
Tobacco	19	---	2/	---	2,511	1,467	---	---	---	---	3,999
Peanuts	---	---	---	---	1,071	3,835	2/	1,084	---	---	5,993
Other field crops	2/	2/	39	62	---	407	118	2/	479	502	1,619
Alfalfa	245	206	470	2/	170	---	24	52	486	615	2,276
Other hay crops and forage	2/	2/	102	---	---	2/	---	36	15	2/	172
Pasture and rangeland	---	---	---	2/	---	31	34	93	---	2/	161
Sugar beets	---	2/	2/	11	---	---	---	---	151	492	660
Potatoes	621	182	---	258	268	91	---	518	548	284	2,770
Other vegetables	1,389	366	1,238	---	395	1,364	126	295	156	2,939	8,268
Citrus fruits	---	---	---	---	---	2,139	---	224	27	659	3,049
Apples	2,403	349	831	2/	359	32	---	---	44	808	4,831
Other deciduous fruits	393	148	62	2/	143	307	33	2/	24	1,976	3,091
Other fruits and nuts	58	72	2/	2/	76	272	122	352	248	1,978	3,183
Nursery and greenhouse crops	150	2/	---	---	20	88	---	---	2/	206	467
Total	5,486	4,271	18,424	7,543	9,966	40,402	32,245	18,465	5,409	12,045	154,256

--- = None reported.

1/ Excludes Alaska and Hawaii; excludes petroleum.

2/ Less than 10,000 pounds.

3/ Barley, oats, and rye.

Appendix table 15--Herbicide use on selected crops, by regions, 1971 1/

Crop	Northeast	Lake	Corn Belt	Northern Plains	Appalachia	Southeast	Delta	Southern Plains	Mountain	Pacific	Total
						1,000 pounds (a.i.)					
Corn	5,250	21,358	54,069	10,700	6,166	2,105	474	127	566	245	101,060
Cotton	---	---	1,176	---	1,039	3,045	9,649	3,952	210	539	19,610
Wheat	2/	639	---	5,013	15	18	---	144	2,853	2,939	11,622
Sorghum	14	---	1,176	5,834	310	125	287	3,486	251	55	11,538
Rice	---	---	---	---	---	---	4,450	2,646	---	889	7,985
Other grains 3/	265	1,210	77	1,831	---	2/	---	30	1,092	865	5,377
Soybeans	207	2,998	18,875	1,054	3,042	1,233	9,011	99	---	---	36,519
Peanuts	---	---	---	---	1,431	2,669	2/	266	2/	---	4,374
Other field crops 4/	126	2,396	152	856	122	1,221	42	---	417	721	6,053
Alfalfa, other hay, and forage	74	14	16	2/	27	35	66	42	36	308	627
Pasture and rangeland	2/	84	212	2,225	167	161	248	4,223	686	324	8,336
Sugar beets	---	340	126	333	---	---	---	---	415	1,763	2,977
Potatoes	1,451	51	---	45	---	64	---	12	318	237	2,178
Other vegetables	296	518	392	---	45	33	33	21	126	1,897	3,361
Citrus fruits	---	---	---	---	---	372	---	---	---	304	676
Apples	128	---	11	---	2/	2/	---	---	---	51	197
All other fruits and nuts	181	57	37	---	2/	149	2/	---	---	1,068	1,503
Summer fallow	---	62	32	331	16	15	---	2/	501	471	1,437
Nursery and greenhouse crops	79	---	---	---	99	2/	---	---	19	29	230
Total	8,078	29,727	76,351	28,231	12,489	11,262	24,267	15,057	7,493	12,705	225,660

--- = None reported.

1/ Excludes Alaska and Hawaii; excludes petroleum.

2/ Less than 10,000 pounds.

3/ Barley, oats, and rye.

4/ Includes tobacco and other field crops.

Appendix table 16--Fungicide use on selected crops, by regions, 1971 1/

Crop	North-east	Lake	Corn Belt	Northern Plains	Appa-lachia	South-east	Delta	Southern Plains	Mountain	Pacific	Total
						1,000 pounds (a.i.)					
Cotton	---	---	---	---	---	60	19	15	12	114	220
Peanuts	---	---	---	---	1,132	2,985	2/	312	---	---	4,431
Potatoes	2,463	82	---	189	304	421	---	88	160	417	4,124
Other vegetables	143	2/	3,513	---	396	1,102	2/	41	27	437	5,666
Citrus fruits	---	---	---	---	---	7,996	---	---	---	1,261	9,257
Apples	2,943	1,026	853	12	1,353	67	---	---	16	937	7,207
Other deciduous fruits	908	111	163	2/	379	249	21	---	---	1,985	3,822
Other fruits and nuts	440	74	---	---	103	442	75	256	99	1,607	3,096
All other crops 3/	160	2/	768	310	122	52	2/	92	31	182	1,732
Total	7,057	1,305	5,297	517	3,789	13,374	127	804	345	6,940	39,555

--- = None reported.

1/ Excludes Alaska and Hawaii; excludes sulfur and petroleum.

2/ Less than 10,000 pounds.

3/ Includes corn, sorghum, wheat, rice, tobacco, soybeans, sugar beets, other grains, other field crops, alfalfa, other hay and pasture, and nursery and greenhouse crops.

Appendix table 17--Use of other pesticides on selected crops, by regions, 1971 1/

Crop	North-east	Lake	Corn Belt	Northern Plains	Appa-lachia	South-east	Delta	Southern Plains	Mountain	Pacific	Total
						1,000 pounds (a.i.)					
Corn	2/	---	2/	386	---	---	---	---	---	56	443
Cotton	---	---	340	---	178	1,323	3,303	7,230	96	6,226	18,696
Wheat	---	---	---	---	---	---	---	---	245	---	245
Soybeans	---	---	2/	---	---	21	25	---	---	---	52
Tobacco	48	---	87	---	6,842	2,443	---	---	---	---	9,420
Peanuts	---	---	---	---	257	68	---	146	---	---	471
Other field crops 3/	---	---	---	---	---	---	---	---	35	411	446
Alfalfa	---	2/	---	---	---	---	---	2/	---	2/	2/
Sugar beets	---	---	2/	994	---	---	---	---	123	994	2,114
Potatoes and vegetables	43	---	---	55	---	2,222	---	2/	2/	8,106	10,435
Citrus fruits	---	---	---	---	---	785	---	---	---	495	1,280
Apples	116	29	36	---	27	2/	---	---	23	310	548
Other deciduous fruits	2/	---	---	---	2/	---	---	---	2/	252	261
Other fruits and nuts	2/	---	---	---	---	2/	---	---	294	1,213	1,511
Nursery and greenhouse crops	18	---	---	---	21	8	---	---	---	297	344
Total	238	29	472	1,435	7,326	6,877	3,328	7,380	821	18,366	46,272

--- = None reported.

1/ Includes miticides, fumigants, desiccants and defoliants, rodenticides, plant growth regulators, and repellents; excludes Alaska and Hawaii; excludes petroleum.

2/ Less than 10,000 pounds.

3/ Includes other grains, other hay, and forage.

Appendix table 18--Insecticide use on selected crops, by regions, 1976 1/

Crop	North-east	Lake	Corn Belt	Northern Plains	Appa-lachia	South-east	Delta	Southern Plains	Mountain	Pacific	Total
					1,000 pounds (a.i.)						
Corn	1,018	5,003	14,091	8,172	940	974	22	1,246	369	144	31,979
Cotton	---	---	---	---	4,092	20,581	32,653	2,461	3,337	1,015	64,139
Wheat	16	14	481	395	165	---	---	4,485	408	1,272	7,236
Sorghum	---	---	300	2,199	---	100	487	1,366	61	91	4,604
Rice	---	---	---	---	---	---	82	426	---	---	508
Other grains 2/	232	---	---	48	---	31	---	1,428	3/	83	1,823
Soybeans	350	22	115	3/	874	6,179	173	151	---	---	7,866
Tobacco	3/	51	21	---	2,259	900	---	---	---	---	3,240
Peanuts	---	---	---	---	1,133	1,049	---	257	---	---	2,439
Alfalfa	953	100	725	196	85	---	---	782	352	2,198	5,391
Other hay crops and forage	21	11	3/	3/	---	310	236	291	11	75	959
Pasture and rangeland	---	---	3/	---	3/	3/	57	50	3/	3/	114
Total	2,599	5,201	15,738	11,013	9,549	30,125	33,710	12,944	4,540	4,879	130,298

--- = None reported.
1/ Excludes Alaska and Hawaii; excludes petroleum.
2/ Barley, oats, and rye.
3/ Less than 10,000 pounds.

Appendix table 19--Herbicide use on selected crops, by regions, 1976 1/

Crop	North-east	Lake	Corn Belt	Northern Plains	Appa-lachia	South-east	Delta	Southern Plains	Mountain	Pacific	Total
					1,000 pounds (a.i.)						
Corn	10,931	33,914	108,037	22,811	19,086	8,126	387	1,664	1,191	914	207,061
Cotton	---	---	---	---	750	1,039	11,562	2,761	1,302	898	18,312
Wheat	2/	2,408	58	6,221	84	---	55	983	3,919	8,145	21,879
Sorghum	127	16	1,300	7,941	1,502	53	420	4,097	216	47	15,719
Rice	---	---	---	---	---	---	6,163	2,289	---	55	8,507
Other grains 3/	405	1,504	157	1,248	131	13	---	77	1,431	510	5,476
Soybeans	1,323	6,052	41,505	2,349	8,211	6,371	15,241	11	---	---	81,063
Tobacco	---	61	16	---	821	311	---	---	---	---	1,209
Peanuts	---	---	---	---	999	2,073	---	285	2/	---	3,366
Alfalfa	50	2/	20	---	---	---	---	---	56	790	918
Other hay and forage	25	2/	41	111	10	54	2/	285	22	164	724
Pasture and rangeland	---	79	4,143	2,538	207	11	84	1,952	324	306	9,644
Total	12,867	44,039	155,277	43,219	31,801	18,051	33,921	14,404	8,470	11,829	373,878

--- = None reported.
1/ Excludes Alaska and Hawaii; excludes petroleum.
2/ Less than 10,000 pounds.
3/ Barley, oats, and rye.

Appendix table 20--Fungicide use on selected crops, by regions, 1976 1/

Crop	North-east	Lake	Corn Belt	Northern Plains	Appa-lachia	South-east	Delta	Southern Plains	Mountain	Pacific	Total
					1,000 pounds (a.i.)						
Corn	2/	2/	10	---	2/	---	2/	---	2/	---	20
Cotton	---	---	---	---	---	---	42	2/	2/	---	49
Wheat	---	---	2/	---	---	---	---	861	2/	---	862
Soybeans	---	---	2/	---	---	41	130	---	---	---	176
Tobacco	---	2/	---	---	153	---	---	---	---	---	154
Peanuts	---	---	---	---	1,142	1,758	---	934	---	---	6,834
Total	2/	2/	16	---	1,299	4,799	172	1,801	2/	---	8,095

--- = None reported.

1/ Excludes Alaska and Hawaii; excludes petroleum and sulfur.

2/ Less than 10,000 pounds.

Appendix table 21--Use of other pesticides on selected crops, by regions, 1976 1/

Crop	Northeast	Lake	Corn Belt	Northern Plains	Appalachia	Southeast	Delta	Southern Plains	Mountain	Pacific	Total
					1,000 pounds (a.i.)						
Corn	---	---	---	---	---	---	---	---	---	483	483
Cotton	---	---	---	---	253	1,481	6,227	1,881	919	1,921	12,682
Sorghum	---	---	266	---	---	---	---	---	---	---	266
Soybeans	---	---	---	---	---	270	1,760	---	---	---	2,030
Tobacco	20	50	55	---	13,654	4,747	---	---	---	---	18,526
Peanuts	---	---	---	---	41	393	---	754	---	---	1,188
Alfalfa	---	---	---	---	---	2/	---	---	2/	122	124
Total	20	50	321	---	13,948	6,892	7,987	2,635	920	2,526	35,299

--- = None reported.

1/ Excludes Alaska and Hawaii; excludes petroleum.

2/ Less than 10,000 pounds.

Appendix table 22--Insecticide use on major field crops, hay, and pasture, by regions, 1982 1/

Crop	Northeast	Lake	Corn Belt	Northern Plains	Appa-lachia	Southeast	Delta	Southern Plains	Mountain 2/	Total
					1,000 pounds (a.i.)					
Corn	558	3,791	16,762	6,212	1,436	587	3/	553	196	30,102
Cotton	---	---	28	---	11	4,280	8,704	1,948	1,953	16,924
Wheat	77	---	---	85	124	---	15	2,283	56	2,640
Sorghum	---	---	3/	1,265	27	60	153	1,040	10	2,559
Rice	---	---	---	---	---	---	135	429	---	564
Other grains 4/	---	---	---	13	22	---	---	155	22	212
Soybeans	161	---	168	---	940	7,077	2,484	244	---	11,074
Tobacco	16	---	11	---	2,466	1,019	---	---	---	3,512
Peanuts	---	---	---	---	568	435	---	32	---	1,035
Alfalfa	1,103	3/	335	209	228	---	60	330	180	2,453
Other hay	---	3/	---	---	11	3/	3/	97	---	117
Pasture	---	---	---	---	---	---	3/	38	---	41
Total	1,915	3,800	17,307	7,784	5,833	13,460	11,567	7,149	2,418	71,233

--- = None reported.

1/ Excludes Alaska, California, Colorado, Connecticut, Hawaii, Maine, Massachusetts, New Hampshire, New Jersey, New Mexico, Nevada, Oregon, Rhode Island, Utah, Vermont, West Virginia, Wyoming; excludes petroleum and sulfur.

2/ Includes Washington State.

3/ Less than 10,000 pounds.

4/ Barley, oats, and rye.

Appendix table 23--Herbicide use on major field crops, hay, and pasture, by regions, 1982 1/

Crop	Northeast	Lake	Corn Belt	Northern Plains	Appa-lachia	Southeast	Delta	Southern Plains	Mountain 2/	Total
					1,000 pounds (a.i.)					
Corn	11,771	45,501	136,601	26,717	16,570	3,655	280	1,499	815	243,409
Cotton	---	---	222	---	811	1,377	9,587	5,176	1,115	18,288
Wheat	45	2,690	62	7,654	517	185	189	610	6,117	18,069
Sorghum	---	---	2,345	7,949	491	178	1,081	3,695	3/	15,738
Rice	---	---	321	---	---	---	10,530	3,238	---	14,089
Other grains 4/	101	1,297	36	1,947	13	3/	3/	73	2,405	5,881
Soybeans	2,694	13,202	57,881	6,432	13,254	13,844	19,085	568	67	127,027
Tobacco	63	---	32	---	1,213	174	---	---	---	1,482
Peanuts	---	---	---	---	1,141	3,304	---	484	---	4,929
Alfalfa	46	28	3/	3/	3/	---	3/	3/	181	271
Other hay	3/	3/	3/	255	16	120	78	203	12	687
Pasture	3/	59	392	2,145	109	39	339	2,008	603	5,698
Total	14,727	62,778	197,894	53,107	34,142	22,884	41,168	17,553	11,315	455,568

--- = None reported.

1/ Excludes Alaska, California, Colorado, Connecticut, Hawaii, Maine, Massachusetts, New Hampshire, New Jersey, New Mexico, Nevada, Oregon, Rhode Island, Utah, Vermont, West Virginia, Wyoming; excludes petroleum and sulfur.

2/ Includes Washington State.

3/ Less than 10,000 pounds.

4/ Barley, oats, and rye.

Appendix table 24--Fungicide use on major field crops, hay, and pasture, by regions, 1982 1/

Crop	Northeast	Lake	Corn Belt	Northern Plains	Appa-lachia	Southeast	Delta	Southern Plains	Mountain 2/	Total
					1,000 pounds (a.i.)					
Corn	---	---	69	---	---	---	---	---	---	69
Cotton	---	---	35	---	16	29	80	3/	12	176
Wheat	---	80	3/	38	---	77	802	3/	---	1,007
Rice	---	---	---	---	---	---	13	67	---	80
Soybeans	---	---	20	---	3/	13	28	3/	---	68
Tobacco	3/	---	13	---	352	87	---	---	---	455
Peanuts	---	---	---	---	478	4,124	---	138	---	4,740
Total	3/	80	147	38	849	4,330	923	213	12	6,595

--- = None reported.

1/ Excludes Alaska, California, Colorado, Connecticut, Hawaii, Maine, Massachusetts, New Hampshire, New Jersey, New Mexico, Nevada, Oregon, Rhode Island, Utah, Vermont, West Virginia, Wyoming; excludes petroleum and sulfur.

2/ Includes Washington State.

3/ Less than 10,000 pounds.

Appendix table 25--Use of other pesticides on major field crops, hay, and pasture, by regions, 1982 1/

Crop	Northeast	Lake	Corn Belt	Northern Plains	Appa-lachia	Southeast	Delta	Southern Plains	Mountain 2/	Total
					1,000 pounds (a.i.)					
Corn	---	---	---	130	---	---	---	---	---	130
Cotton	---	---	43	---	100	453	2,502	2,894	2,247	8,239
Sorghum	---	---	---	---	---	---	44	---	---	44
Rice	---	---	---	---	---	---	3/	3/	---	17
Soybeans	---	---	3/	---	3/	3/	2,309	---	---	2,315
Tobacco	3/	---	28	---	11,232	677	---	---	---	11,946
Peanuts	---	---	---	---	204	1,403	---	19	---	1,627
Total	3/	---	72	130	11,540	2,533	4,863	2,922	2,247	24,317

--- = None reported.

1/ Excludes Alaska, California, Colorado, Connecticut, Hawaii, Maine, Massachusetts, New Hampshire, New Jersey, New Mexico, Nevada, Oregon, Rhode Island, Utah, Vermont, West Virginia, Wyoming; includes miticides, fumigants, desiccants and defoliants, rodenticides, plant growth regulators, and repellents; excludes petroleum and sulfur.

2/ Includes Washington State.

3/ Less than 10,000 pounds.

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